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NASA TM X-202

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TECHNICAL MEMORANDUM

X-202

Declassified by authority of NASA
Classification Change Notices No. 214
Dated ** 15 SEP 1971

AN INVESTIGATION OF THE STATIC STABILITY AND CONTROL CHARACTERISTICS OF WINGED AND WINGLESS INTERCEPTOR MISSILE MODELS

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N71-73441
(ACCESSION NUMBER)
46
(PAGES)
(NASA CR OR TMX OR AD NUMBER)
(THRU)
None
(CODE)
(CATEGORY)
FACILITY FORM 602

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON
December 1959

CONFIDENTIAL

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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AN INVESTIGATION OF THE STATIC STABILITY AND CONTROL CHARACTERISTICS OF WINGED AND WINGLESS INTERCEPTOR MISSILE MODELS*

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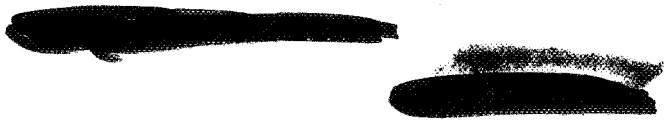
SUMMARY

The static stability and control characteristics of three winged and two wingless missile models considered to be representative of interceptor missiles and perhaps of air-launched ballistic missiles has been investigated. The Mach number range of the investigation was from 0.82 to 3.05 at angles of attack up to about 13° in the 26-inch Langley transonic blowdown tunnel and the 9- by 12-inch blowdown tunnel. The Reynolds number range based on model length of 10 inches was from 6.5×10^6 to 11.3×10^6.

The results of the investigation indicated that the two wingless missile models had nonlinear pitching-moment-coefficient curves at all Mach numbers investigated. It was suggested that these nonlinear characteristics might preclude the successful use of these two wingless shapes as interceptor missiles. The winged missiles were stable at the supersonic Mach numbers and generally had nearly linear variations of pitching-moment coefficient with normal-force coefficient. Trim normal-force coefficients of 4.5 and 3.5 were obtained at transonic and supersonic speeds, respectively, with a combination of canard and trailing-edge controls. The center-of-gravity locations for neutral stability varied from about 45 to 55 percent of the missile length.

INTRODUCTION

The advent of the intercontinental ballistic missile (ICBM) has introduced the problem of a defense against this weapon. Several studies of the aerodynamic and stability characteristics (refs. 1 to 5)



of interceptor missiles or anti-ICBM and the flight paths of such missiles (refs. 6 and 7) have been conducted by the National Aeronautics and Space Administration. These studies have served to define the aerodynamics of hypersonic missiles and to point out certain control problems (ref. 8).

It is the purpose of this paper to present the static stability and control characteristics of two winged models and the static stability of one winged and two wingless missile models believed to be suitable for use as interceptor missiles. The data presented may also be applicable to the control problems of air-launched ballistic missiles. One wingless model was designed to represent a 3-stage missile and the other was the upper two stages of this same missile. The winged models represent 2-stage vehicles consisting of a controllable booster stage and a warhead stage. The Mach number range of the investigation was from 0.82 to 3.05 at angles of attack from about -3° to 13°. The Reynolds number range based on model length varied from 6.5×10^6 to 11.3×10^6.

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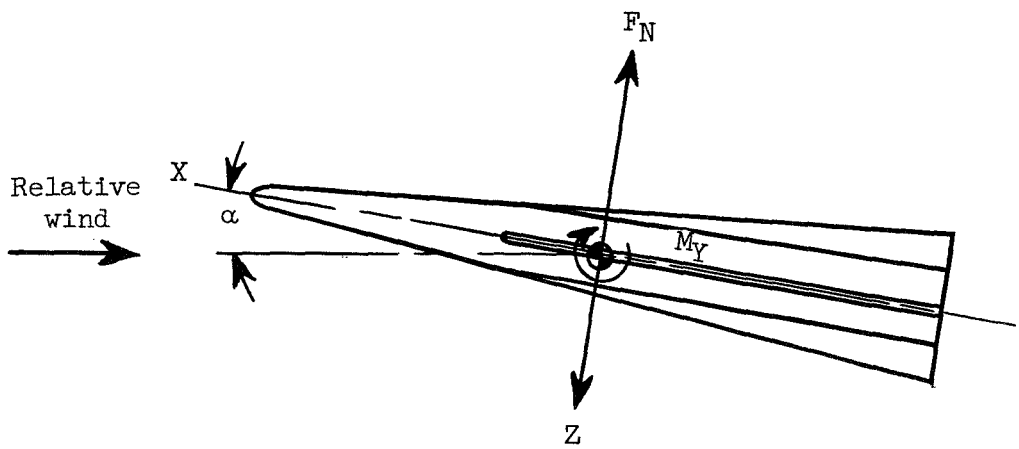
SYMBOLS

The coefficients presented in this paper are based on the body-axis system as indicated in the following sketch:



A — model cross-sectional area, $\frac{\pi d^2}{4}$

C_l — rolling-moment coefficient, $\frac{M_X}{qAd}$

	C_m	pitching-moment coefficient, $\frac{M_Y}{qAd}$
	C_N	normal-force coefficient, $\frac{F_N}{qA}$
	C_n	yawing-moment coefficient, $\frac{M_Z}{qAd}$
L 6 5 1	C_Y	lateral-force coefficient, $\frac{F_Y}{qA}$
	D	diameter
	d	model reference diameter, base diameter for all missiles
	l	model length
	F_N	normal force
	F_Y	lateral force
	g	acceleration due to gravity
	M	Mach number
	M_X	rolling moment
	M_Y	pitching moment
	M_Z	yawing moment
	N_{Re}	Reynolds number
	p_t	tunnel stagnation pressure, lb/sq in. abs
	q	free-stream dynamic pressure
	R	radius
	α	angle of attack of missile center line

δ control deflection angle (see following paragraph), positive trailing edge down for pitch and trailing edge left for yaw

ϕ roll angle of missile

The various control surfaces are designated as follows: With the model oriented so that the canard controls are vertical and horizontal, $\phi = 0^\circ$, the canard surfaces in the XY-plane are called the pitch canard surfaces and the deflection is designated δ_{cp}. The canard surfaces in the XZ-plane are called yaw canard surfaces, and the deflection is designated δ_{cy}.

When the model is rolled to $\phi = 45^\circ$, the wings are in the vertical and horizontal planes and the trailing-edge controls are then designated δ_{ep} and δ_{ey}. When $\phi = 45^\circ$, the four canard surfaces could all be deflected to give pitch, and for these cases the deflections δ_{cp} and δ_{cy} would all have the same sign.

Whenever δ_c and δ_e appear alone, the reference is to all four control surfaces.

APPARATUS AND METHODS

Models

Sketches of models 1 to 4 used in the investigation are presented in figure 1. Photographs of all five models with model 4 shown mounted on the tunnel sting support system are given as figure 2. Models 1, 4, and 5 are winged and models 2 and 3 are wingless. Models 4 and 5 are the only configurations with movable controls, and they are identical except that model 5 had the trailing-edge controls interdigitated with the 85° sweptback wings. This interdigitated position alined the trailing-edge controls with the canard surfaces as shown in figure 2(c). It should be noted that there was no gap between the trailing-edge control and the body when this control was deflected.

Model 2 was designed to represent a 3-stage wingless missile similar to one proposed in reference 8. Model 3 was the upper two stages of model 2. Model 1 was identical to the model with 5° fins reported in references 1, 3, and 5.

All of the models had transition fixed at the shoulder of the hemispherical noses. The grain size used was No. 180 carborundum which ranged in size from 0.003 to 0.005 inch in diameter.

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Test and Measurements

The investigation was conducted in the 26-inch Langley transonic blowdown and 9- by 12-inch blowdown tunnels at Mach numbers from 0.82 to 3.05. The Mach number of the transonic blowdown tunnel was set at 0.82, 1.0, and 1.19 by changing orifice opening. Mach numbers of 1.93, 2.55, and 3.05 were obtained in the 9- by 12-inch blowdown tunnel by using interchangeable nozzle blocks. The test conditions for each model are presented in the following table:

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Models	M	p_t, lb/sq in. abs	N_{Re}	α, deg
5	0.82	32	8.3×10^6	0 to 10.9
5	1.00	27	7.55×10^6	0 to 9.6
5	1.19	25	7.10×10^6	0 to 13.1
1 to 5	1.93	50	11.3×10^6	-1 to 11.7
1 to 5	2.55	50	8.76×10^6	-2.2 to 13
1 to 5	3.05	50	6.46×10^6	-3.3 to 13.3

The models were mounted on a five-component internal strain-gage balance which did not have an axial-force beam. The forces and moments were determined from the output of self-balancing potentiometers which were recorded on pen-type strip charts. The raw data were reduced to standard coefficients by automatic computing machines. The angle-of-attack data were corrected for sting and balance deflections under load and for a tunnel downflow angle of 0.5° at a Mach number of 3.05.

The estimated maximum errors of the quantities presented in this paper are as follows:

C_l	± 0.02
C_m	± 0.10
C_N	± 0.02
C_n	± 0.10
C_Y	± 0.02
M	± 0.02
α, deg	± 0.10
δ, deg	± 1.0

RESULTS AND DISCUSSION

Basic Data

The variation of normal-force and pitching-moment coefficient with angle of attack for models 1 to 4 is shown in figure 3. A comparison of the data for model 1 with data from reference 1 for a similar model is shown in figure 3(a), and these data are in fair agreement. The winged configurations are stable about the selected center-of-gravity position (0.50$\bar{l}$), and the pitching-moment curves are nearly linear; however, the wingless configurations (models 2 and 3) are unstable.

The effect of control deflection on the normal-force-coefficient and pitching-moment-coefficient characteristics with angle of attack is shown in figure 4 for model 4 at $M = 3.05$. Deflection of the pitch canard controls with the model at $\phi = 0^\circ$ produces a sizeable increment in normal-force coefficient with only a small change in pitching-moment coefficient (fig. 4(a)). The opposite trend is shown in figure 4(b) in which the model is rolled to $\phi = 45^\circ$ and the trailing-edge controls are deflected. The increment in normal-force coefficient due to control deflection is small, and a sizeable increment in pitching-moment coefficient is produced. Some reflexes in the pitching-moment curves are noted in figure 4(b); whereas only increased stability is noted in figure 4(a) with an increase in α.

When the model was rolled to $\phi = 45^\circ$, the four canard surfaces could be rotated to give pitch control, and figure 4(c) contains data obtained with the canard surfaces deflected and the trailing-edge controls undeflected. The pitching-moment-coefficient curves are nonlinear, and, in fact, for positive deflections there is a tendency towards instability in the curve and an unstable slope above an angle of attack of about 8°. These nonlinearities in the pitching-moment-curve slopes are undesirable, but configurations similar to the model may not be unusable inasmuch as automatic stability would be employed in such a missile. The deflection of trailing-edge controls in addition to the deflection of the canard controls is shown in figure 4(d). Deflection of the trailing-edge controls (45° out of the plane of the canard surfaces) caused small decrements in the normal-force coefficients as would be expected and sizeable increments in pitching-moment coefficient. It appears that the lift carried on the trailing-edge controls has shifted the aerodynamic center slightly rearward from that shown in figure 4(c) and produced slightly more linear pitching-moment curves.

Commands to a missile such as model 4 to proceed to a target misalined with the missile in both pitch and yaw or yaw alone might require controls deflection such as are shown in figure 5. Deflection of only the trailing-edge yaw controls as shown in figure 5(a) causes no change

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in missile pitch characteristics from that of undeflected controls. When the trailing-edge pitch and yaw controls were deflected together with the canards undeflected as in figure 5(b), there were no significant interferences on the effectiveness of the pitch controls. Similarly, the data shown in figures 5(c) and 5(d) show no significant interferences on the pitch characteristics when the canard controls were deflected in yaw alone, pitch alone, or in combination pitch and yaw.

The variation of normal-force coefficient and pitching-moment coefficient with angle of attack for model 5 is shown in figure 6 for several Mach numbers. Model 5 was considered to be representative of an air-launched ballistic missile as well as an anti-ICBM missile.

The air-launched ballistic missile must perform a manuever very similar to that shown in reference 6 for the anti-ICBM missile except that it may be required to make a high g turn from the horizontal to a ballistic path at transonic or low supersonic speeds. Therefore, the air-launched ballistic missile may actually have to produce a higher trim normal-force coefficient than the anti-ICBM missile. Data shown in reference 9 indicated that a trailing-edge control interdigitated with the main wing or fins produced higher values of trim normal-force coefficient than with the control in line with the fins as in model 4; therefore, the trailing-edge controls of model 5 were placed in the plane of the canards (see fig. 2(c)). Figure 6(a) shows data for model 5 for no controls deflected and only the canard control deflected 20°. The effectiveness of the canard control in producing normal force falls rapidly with angle of attack until at 9° it is only one-half as effective as at 1°. This loss in effectiveness is probably caused by flow separation from the canard surfaces at the higher angles of attack. The pitching-moment curves are nonlinear and have unstable slopes near 0° angle of attack. The data for Mach numbers of 1.0 and 1.19 are similar to that shown for a Mach number of 0.82 except that the deflected canard surface does not lose effectiveness and the aerodynamic center has moved slightly rearward. Data are shown for both the canard surface and trailing-edge control deflected in figure 6(d). The data are fairly linear and the deflected trailing-edge control produces a sizeable increment in pitching moment, an important advantage for trim conditions to be shown later.

Figure 7 shows the variation of lateral stability coefficients with angle of attack for model 4 with various control deflections. The rolling-moment coefficient induced by interferences when the controls are deflected is shown to be small for the trailing-edge controls (fig. 7(a)) and moderate for the canard surfaces (figs. 7(b) and 7(c)). The pitch canard surfaces have only a small effect on the rolling-moment coefficients inasmuch as only small differences were shown with or without the pitch canard surfaces deflected. The yaw canard surfaces appear to induce the largest values of rolling-moment coefficient and to

produce only small values of yawing-moment coefficient because of the location relative to the selected moment center. (See fig. 1.)

Static Stability

The variation of pitching-moment coefficient with normal-force coefficient is shown in figure 8 for all models. Model 5 is shown to be unstable and nonlinear about $0.50l$ at the transonic Mach numbers. Models 2 and 3 are unstable about $0.50l$ and nonlinear at all Mach numbers investigated. The unstable tendency can be corrected by proper center-of-gravity location; however, the nonlinear tendency would present a serious problem for the designer of rocket motor controls. The wingless anti-ICBM missile depends upon attaining a high angle of attack to produce the high normal accelerations required to intercept the ICBM. (See ref. 8.) The nonlinear pitch characteristics of this particular cone-cylinder model could preclude its successful use inasmuch as it would require an excessive amount of control. Models 1, 4, and 5 are stable at all the test supersonic Mach numbers with linear characteristics (figs. 8(a) to 8(d) and 8(f)). It should be noted that the $\phi = 45^\circ$ roll position produces a tendency towards instability at the higher normal-force coefficients for both models 1 and 4. This result may be caused by shadowing of the two upper wings or canard surfaces by the body or adverse cross-flow effects when the body is at angle of attack.

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Control Effectiveness

The control effectiveness, variation of C_m and C_N with δ, is shown in figure 9 for models 4 and 5 at $M = 3.05$ and $\alpha = 0^\circ$. The most effective control for producing normal force was found for model 4 when all four canard surfaces were deflected to provide pitch control ($\phi = 45^\circ$); however, practically no change in pitching moment occurred. The largest pitching-moment increment was produced by the combination of two canard surfaces deflected and trailing-edge controls in the plane of the canards (fig. 9(e)). The desirability of these characteristics will be discussed in the subsequent analysis of trim.

Trim Characteristics

The effect of center-of-gravity location on the trim normal-force coefficient and the angle of attack for trim is shown in figure 10. The dashed portions of the curves define the characteristics near neutral stability where it is difficult to define the exact trim point. The data indicate that model 5 could be trimmed at normal-force coefficients of about 4.8 and 4.2 for Mach numbers of 1.00 and 1.19, respectively.

The corresponding angles of attack are about 12.8° and 11°. Unfortunately, the center-of-gravity position for neutral stability is ahead of 0.50l, and a practical center-of-gravity position would probably be about 0.60l. These data indicate that a better configuration for model 5 for transonic turns would have located the hinge lines of the canard surfaces about 10 percent of the body length more rearward.

In the discussion of figure 6(d), it was noted that the trailing-edge control produced an important pitching-moment increment. The importance of this sizeable pitching-moment increment is better understood when the data in figure 10(b) are reviewed. When the trailing-edge control is undeflected, the normal-force coefficient at trim is about 1.8 at 0.50l. The center of gravity for neutral stability moves forward slightly when the trailing-edge control is deflected to -15°; however, $C_{N,trim}$ is about 3.5 at 0.50l. This represents an ability to trim at an angle of attack of more than twice that for trim with an undeflected trailing-edge control. For some of the flight paths shown in reference 6, it represents the difference between success and failure.

Figure 10(c) shows data for model 4 at $\phi = 0°$ and 45°. At $\phi = 0°$ the two pitch canards only were deflected and trim values of C_N were about 3.5 with a very small static margin; however, the center of gravity could be located as far rearward as 0.55l and still maintain positive stability. At $\phi = 45°$, the trailing-edge pitch controls only were deflected and substantially lower $C_{N,trim}$ were obtained. This result is similar to that reported in references 5 and 8. When all four canards were deflected for pitch control there was a noticeable lack of change in C_m (fig. 4) and this lack of rotation in the pitch plane produces very small trim angles of attack and normal-force coefficients (fig. 10(d)). Both α_{trim} and $C_{N,trim}$ are improved when the trailing-edge controls are deflected with the four canards; however, the center-of-gravity location for neutral stability was about 0.45l.

It is suggested by these data that a better configuration than any investigated herein may be constructed if the canard surfaces were moved rearward and the trailing-edge controls were alined with the canard surfaces as for model 5. This modification should move the center of gravity for neutral stability rearward and provide significant pitch increments when the canard is deflected. Another possible improvement may be the deflection of two canard surfaces and all four trailing-edge controls on model 4 to give pitch control in the $\phi = 0°$ roll position.

CONCLUDING REMARKS

The static stability and control of a series of three winged and two wingless models considered to be representative of interceptor missiles and perhaps air-launched ballistic missiles has been investigated at Mach numbers from 0.82 to 3.05 in the 26-inch Langley transonic and 9- by 12-inch blowdown tunnels. The wingless models, one of which represented a 3-stage anti-ICBM missile, and the other its upper two stages, had nonlinear variations of pitching-moment coefficient with normal-force coefficient at all Mach numbers investigated. It was suggested that these nonlinear characteristics might preclude the successful use of these models as interceptor missiles. The winged missiles were stable and generally had nearly linear variations of pitching-moment coefficient with normal-force coefficient at the supersonic Mach numbers. Trim normal-force coefficients of 3.5 were obtained for a configuration with canard surfaces and trailing-edge controls deflected simultaneously where the canard controls were rotated 45° out of the plane of the wings and trailing-edge controls. Trim normal-force coefficients of about 4.5 were obtained at transonic speeds for a similar configuration except that the trailing-edge controls were located in the plane of the canard surfaces (45° out of the plane of the wings). The center-of-gravity location for neutral stability varied from about 45 to 55 percent of the missile length. The results indicate that a better configuration might have been obtained if the canard surfaces on the latter configuration had been located farther to the rear.

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., September 8, 1959.

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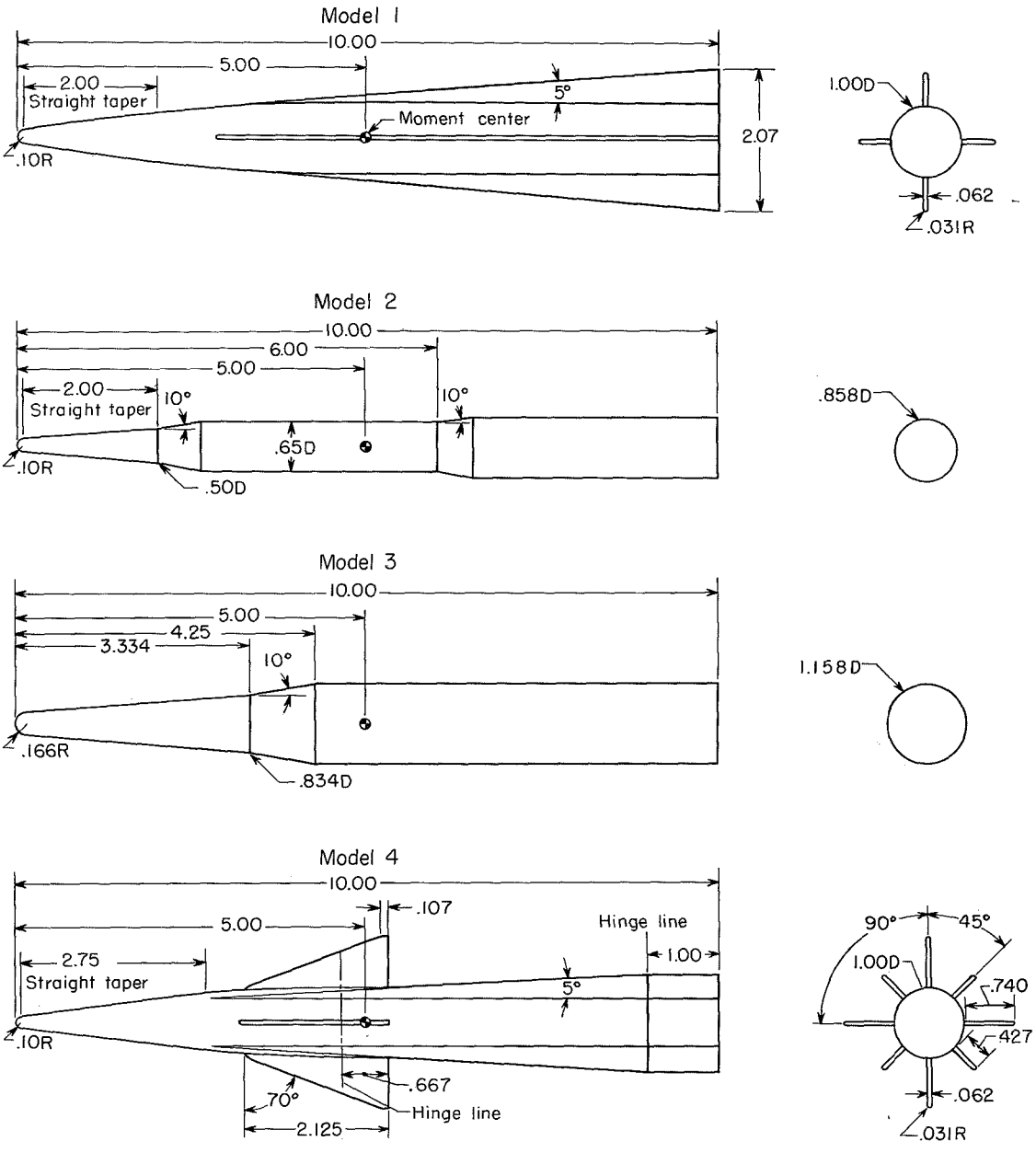
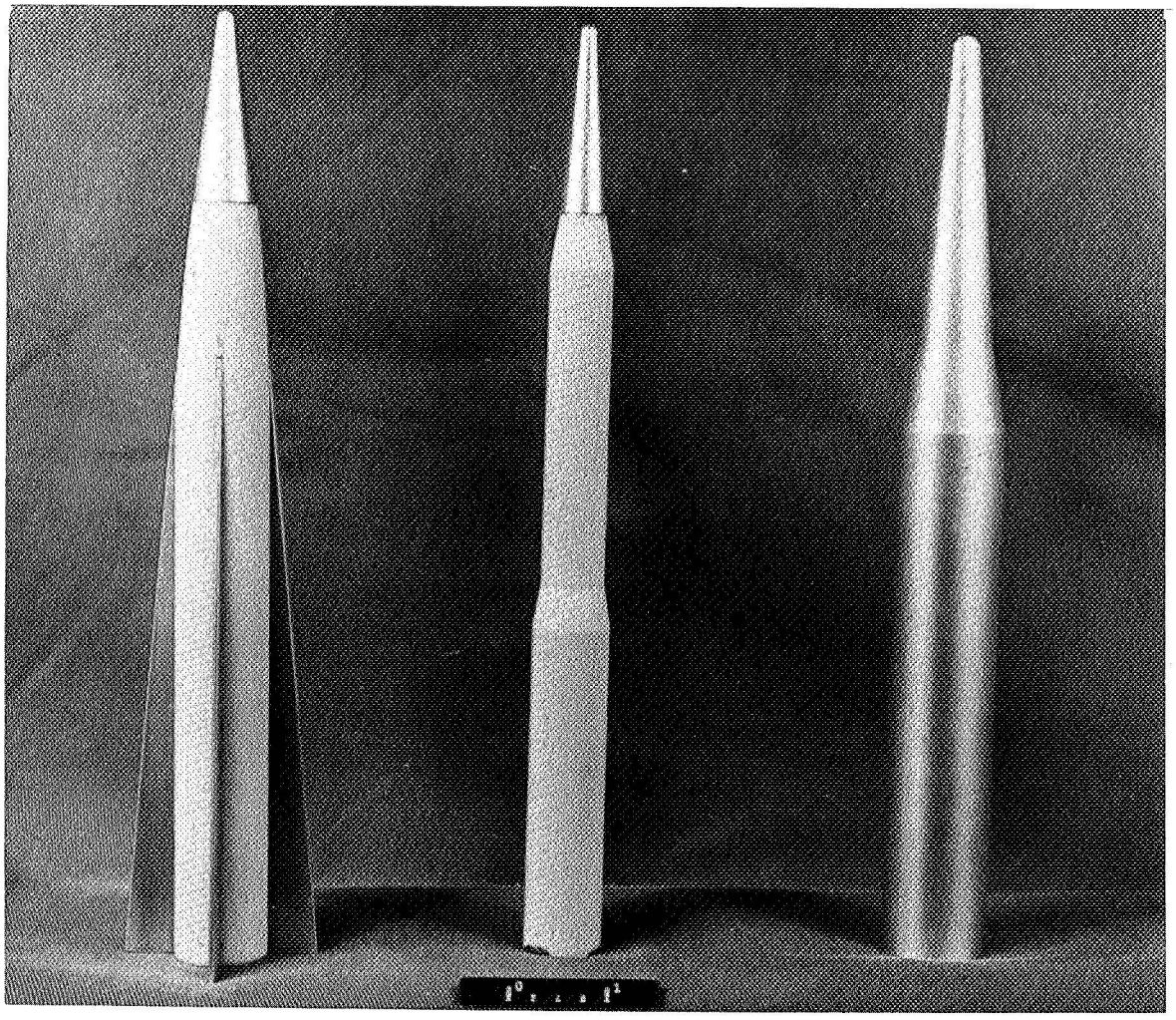


Figure 1.- Model geometry. All dimensions in inches unless otherwise shown.



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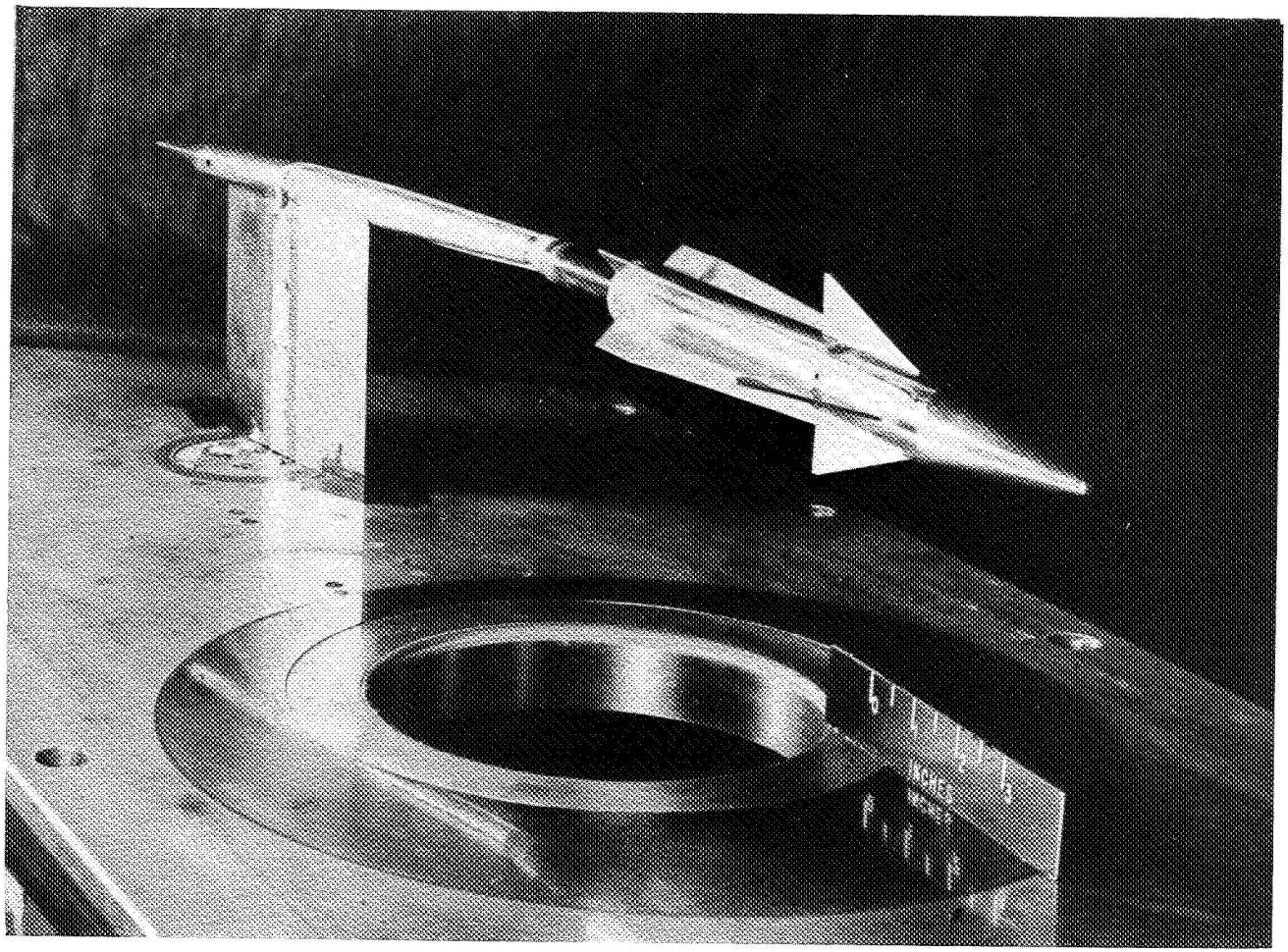
(a) Models 1, 2, and 3. L-58-3175

Figure 2.- Photographs of models.



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(b) Model 4 mounted on tunnel sting support system at $\phi = 0^{\circ}$.

Figure 2.- Continued.

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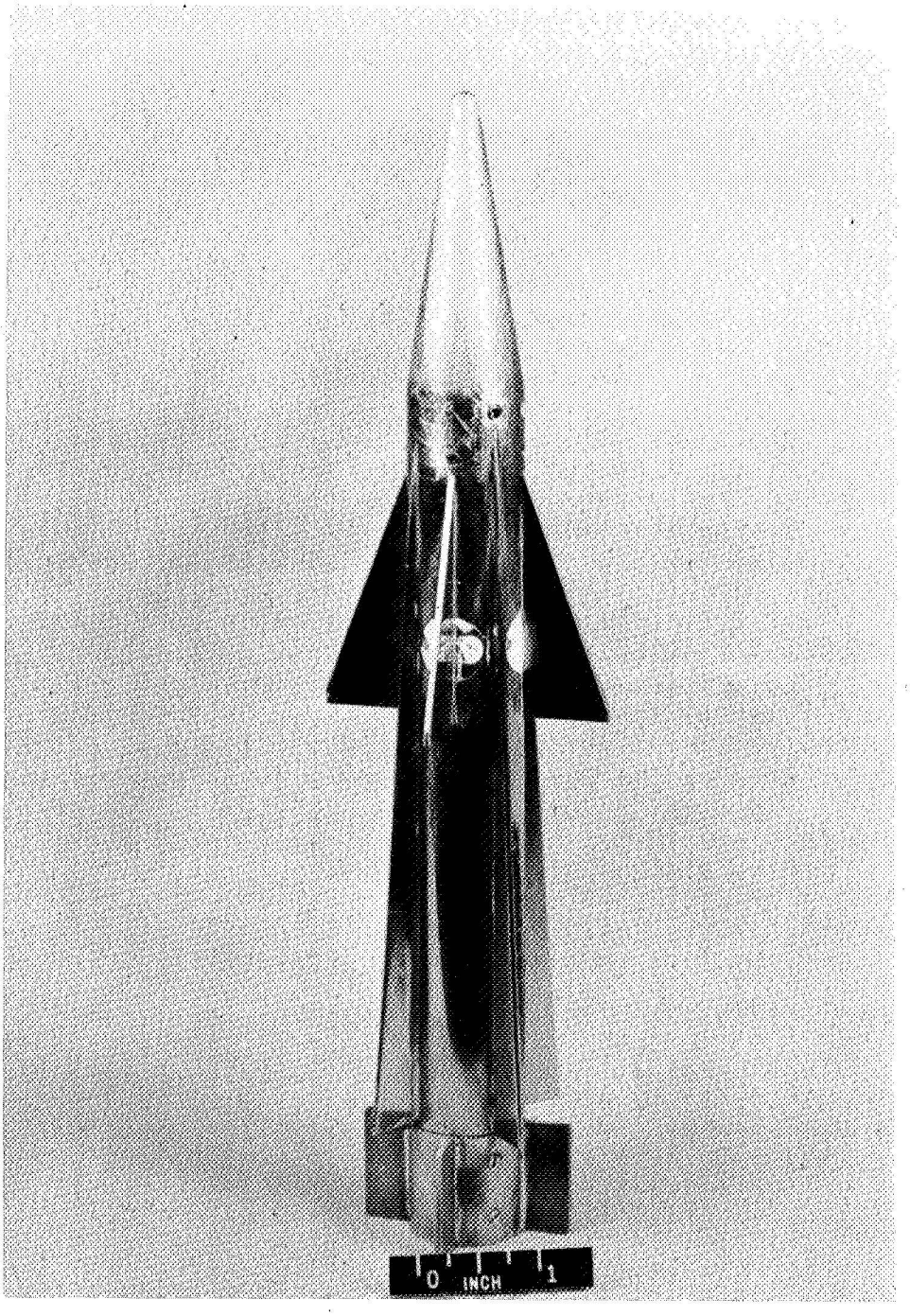
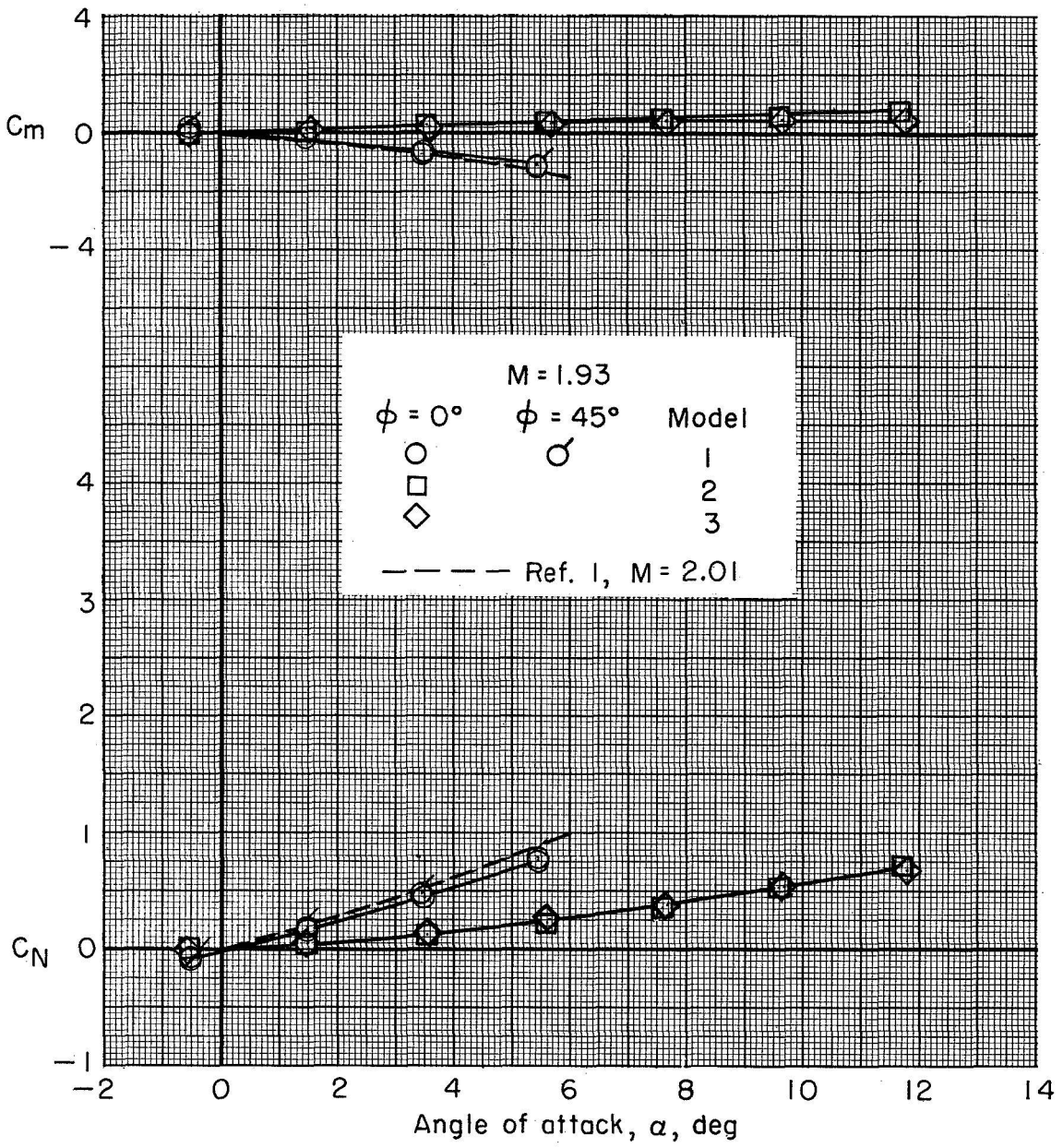


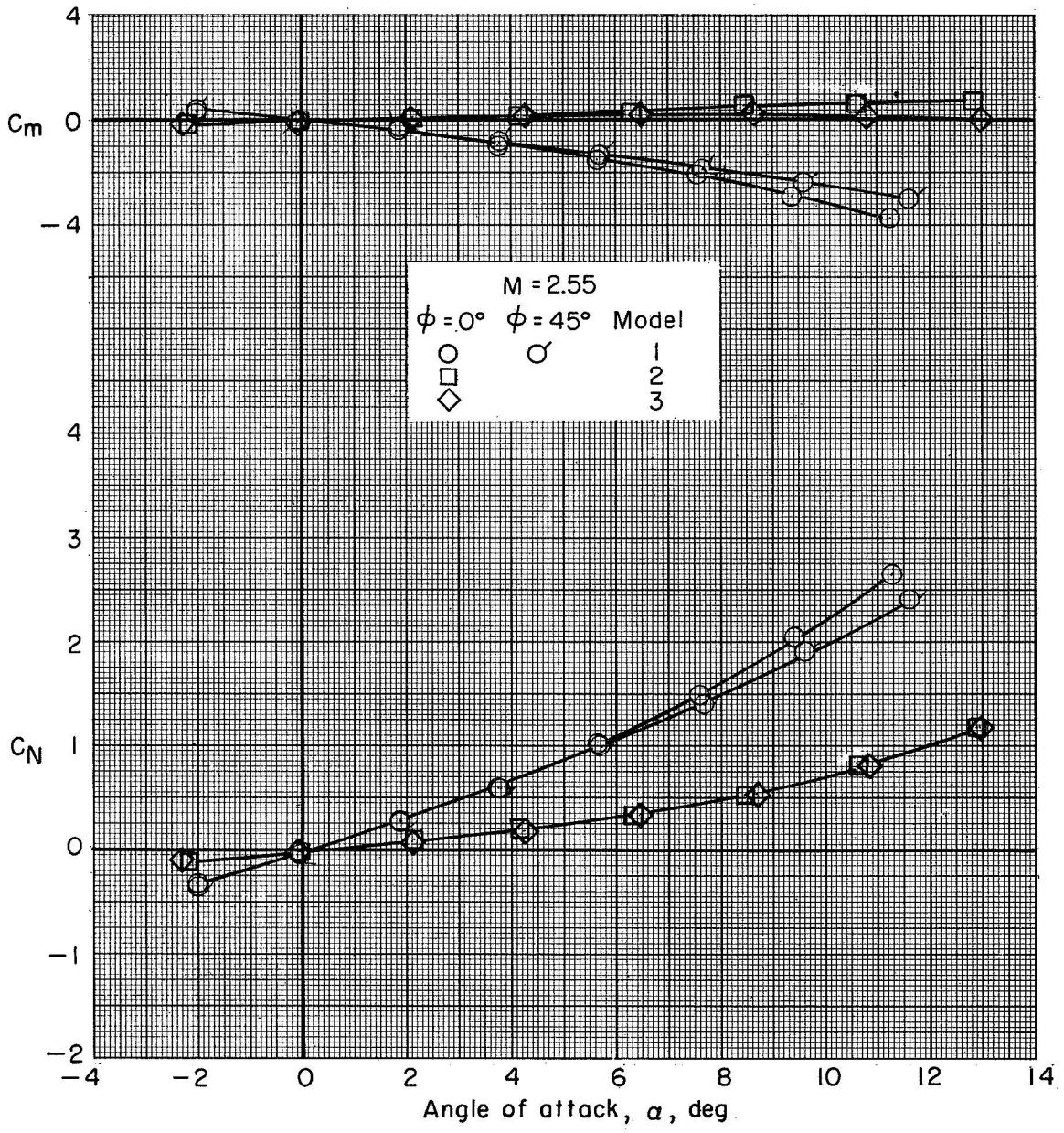
(c) Model 5. L-59-3165

Figure 2.- Concluded.



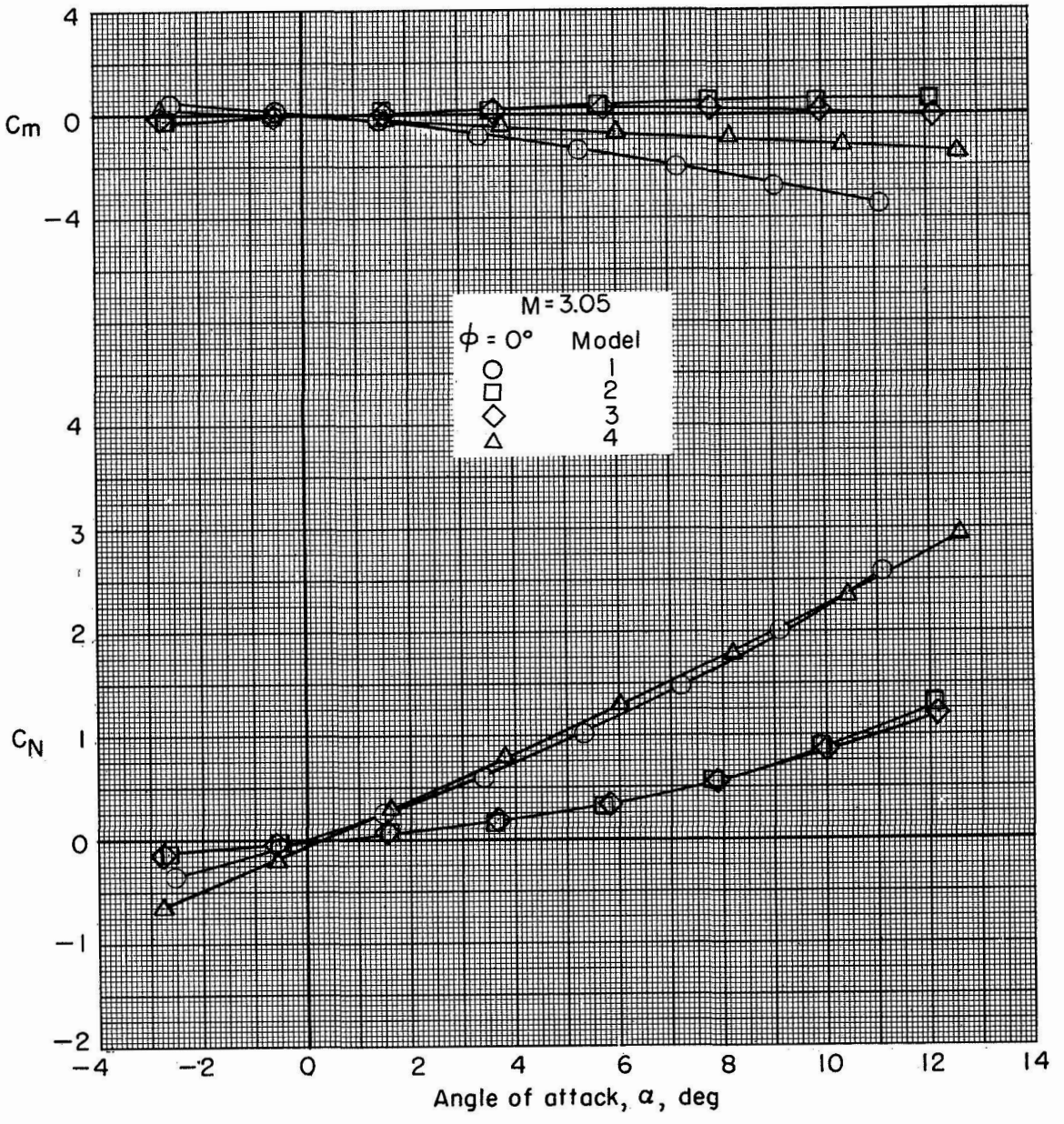
(a) Models 1, 2, and 3.

Figure 3.- Variation of normal-force and pitching-moment coefficients with angle of attack, no controls deflected.



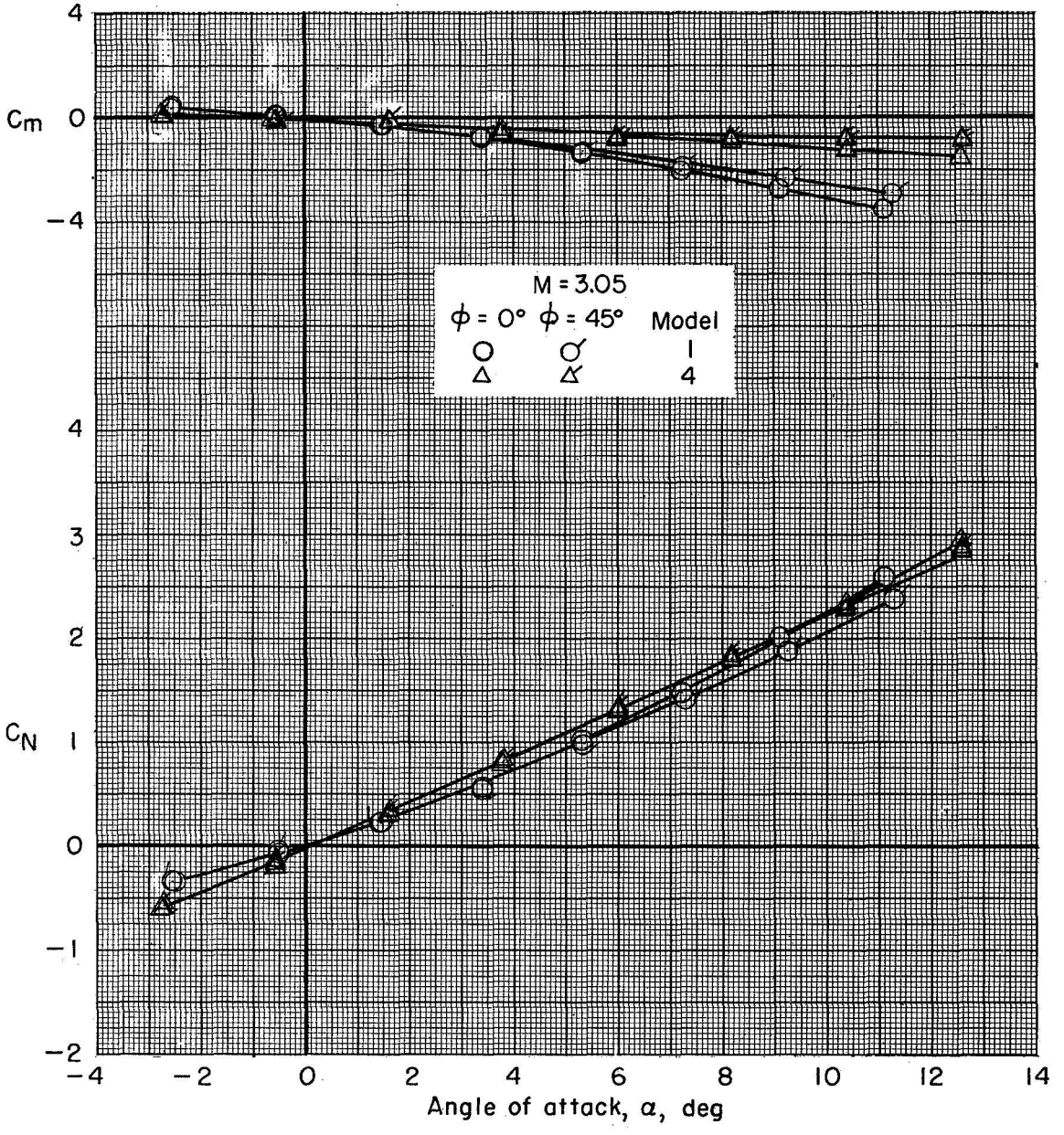
(b) Models 1, 2, and 3.

Figure 3.- Continued.



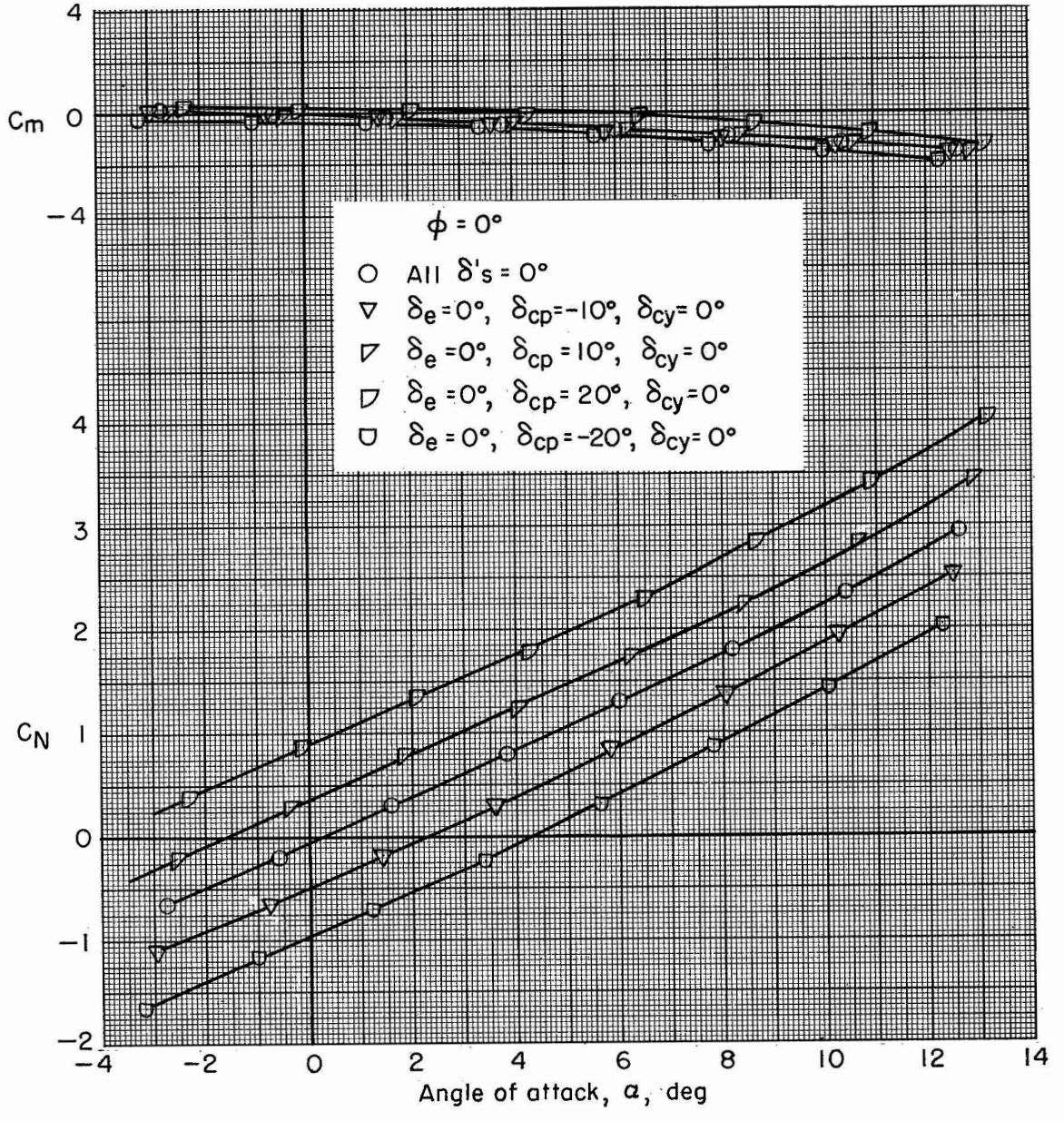
(c) Models 1, 2, 3, and 4.

Figure 3.- Continued.



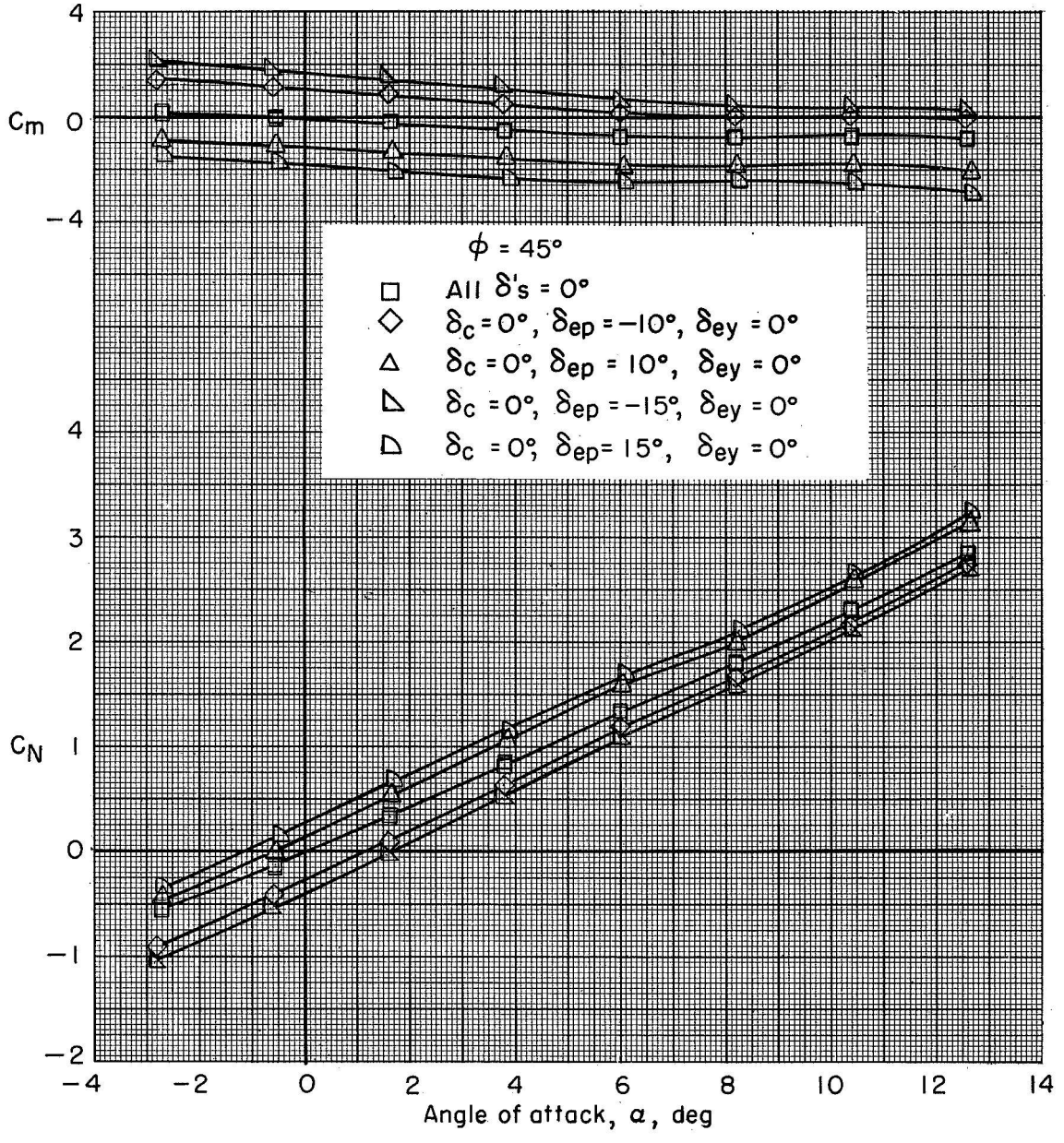
(d) Comparison of models 1 and 4.

Figure 3.- Concluded.



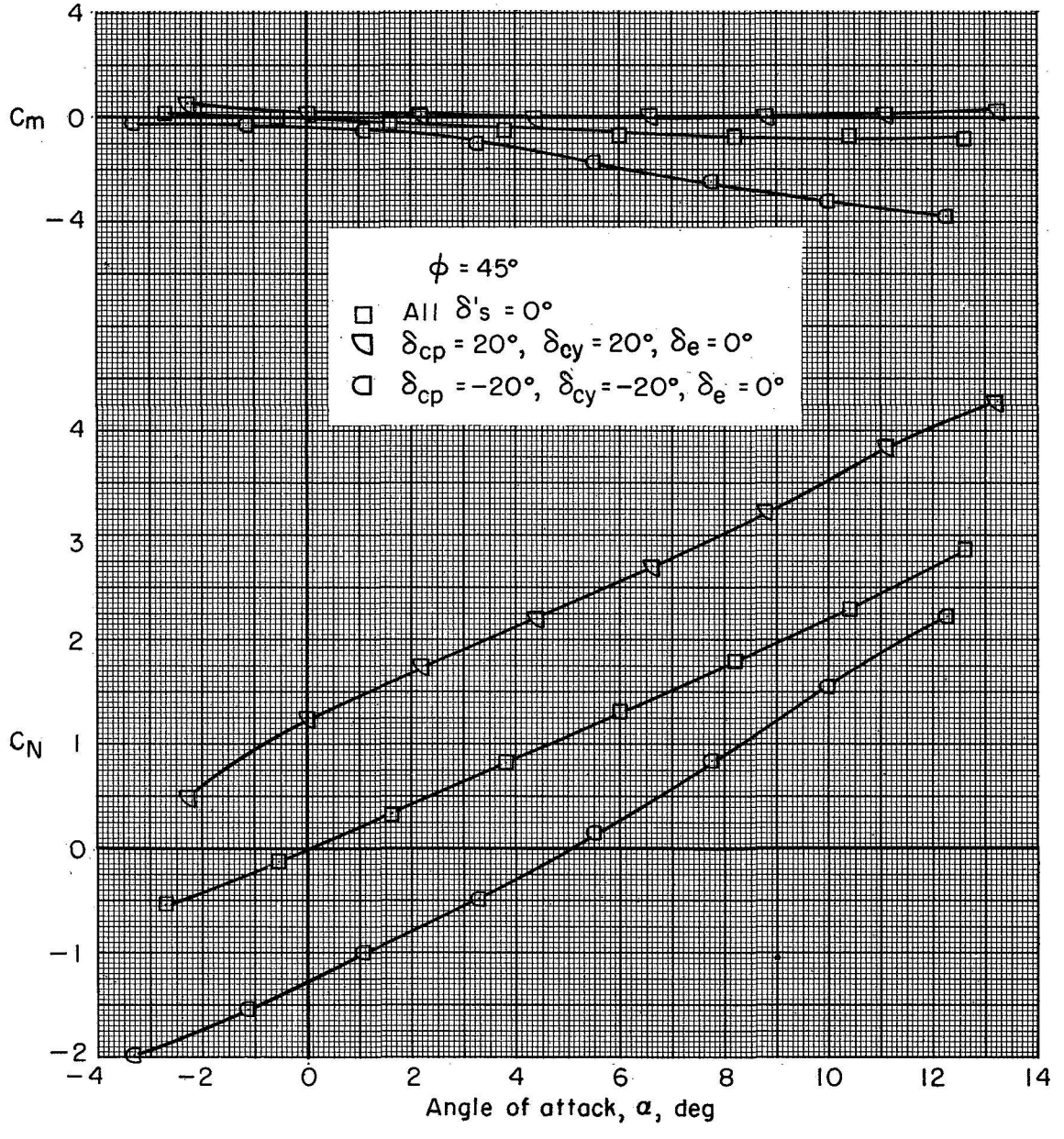
(a) Pitch canard controls only deflected.

Figure 4.- Variation of normal-force and pitching-moment coefficients with angle of attack for model 4 at M = 3.05.



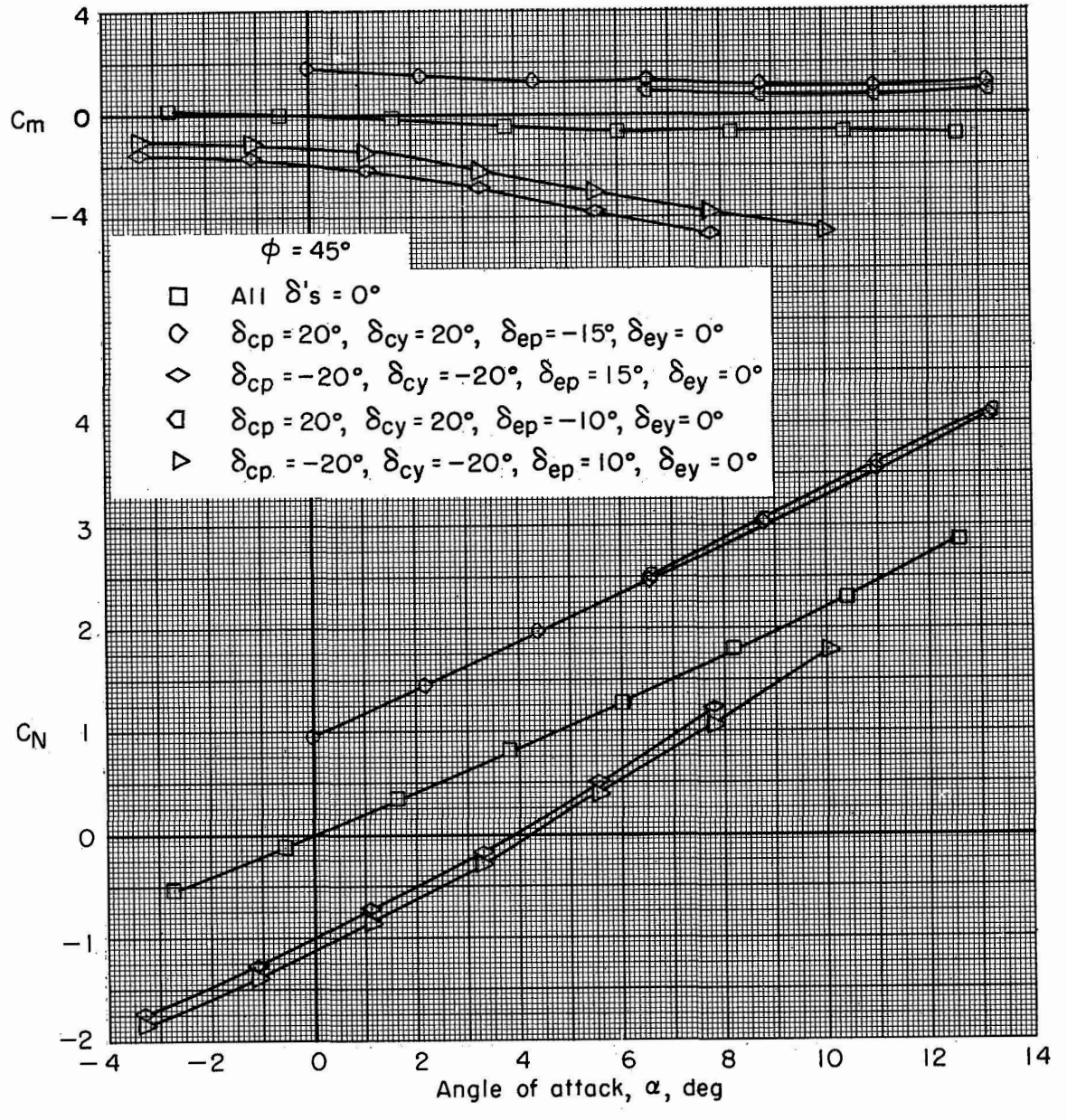
(b) Trailing-edge pitch controls deflected.

Figure 4.- Continued.



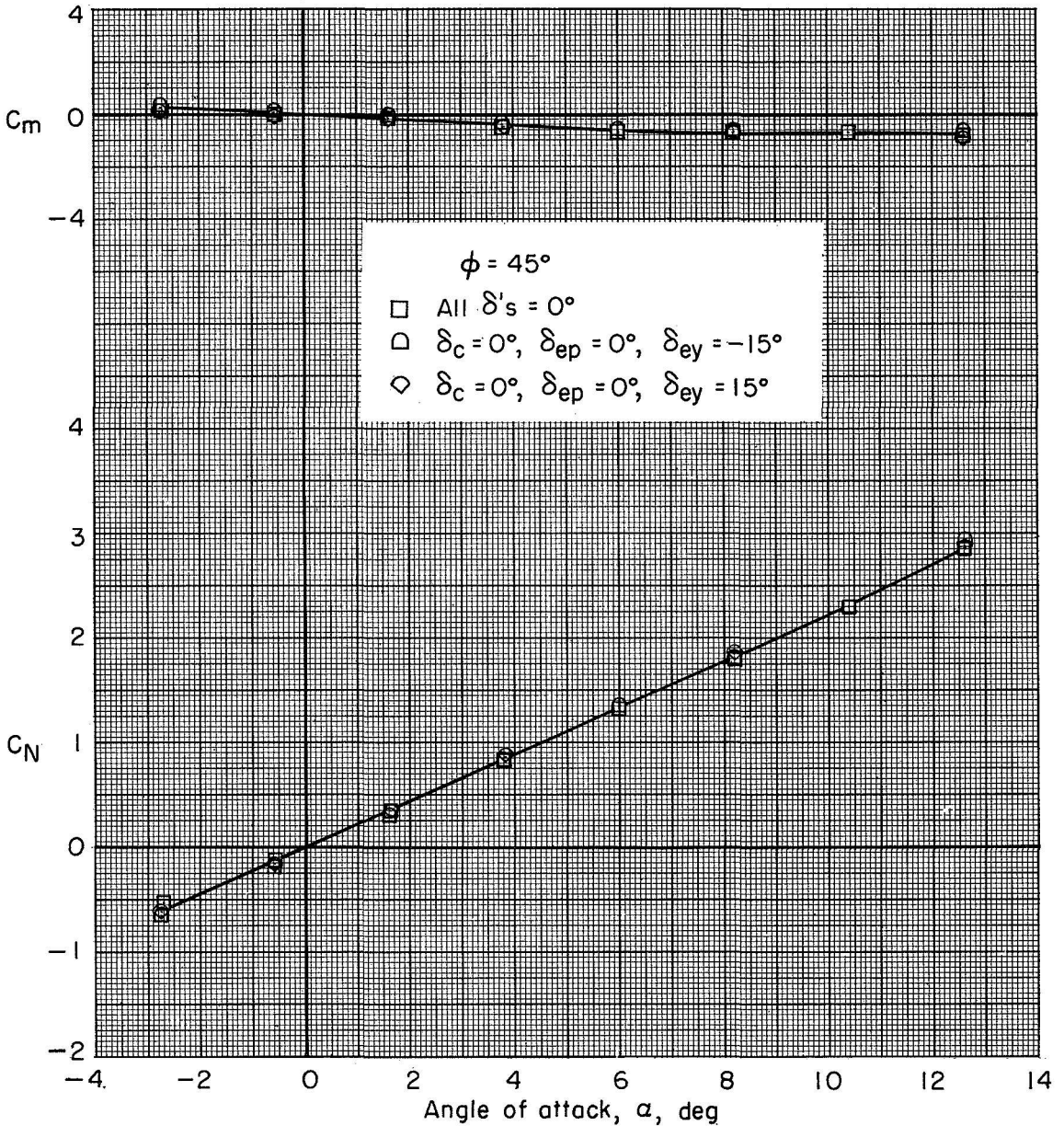
(c) All four canard controls deflected for pitch.

Figure 4.- Continued.



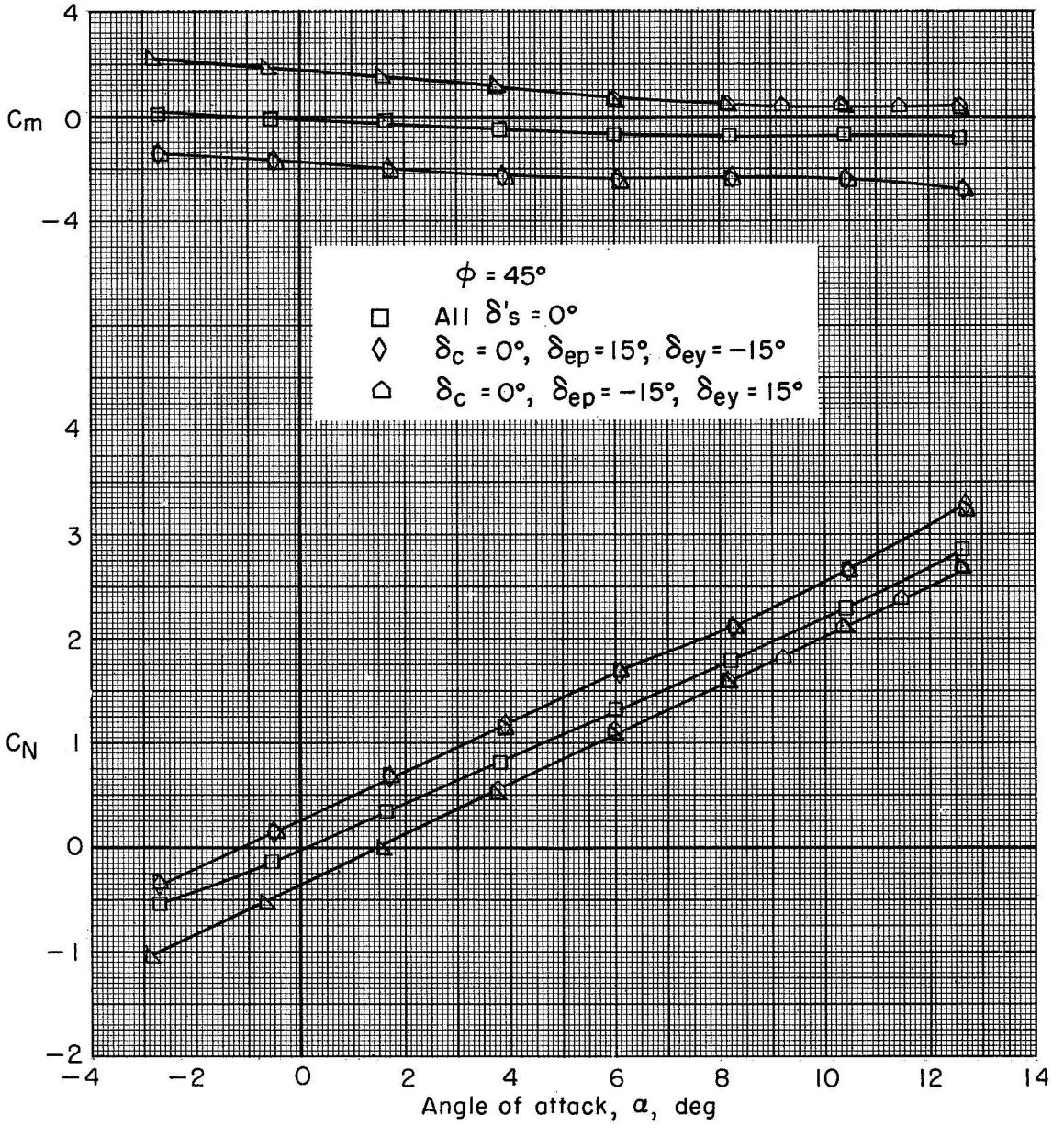
(d) All four canard surfaces and two trailing-edge controls deflected for pitch.

Figure 4.- Concluded.



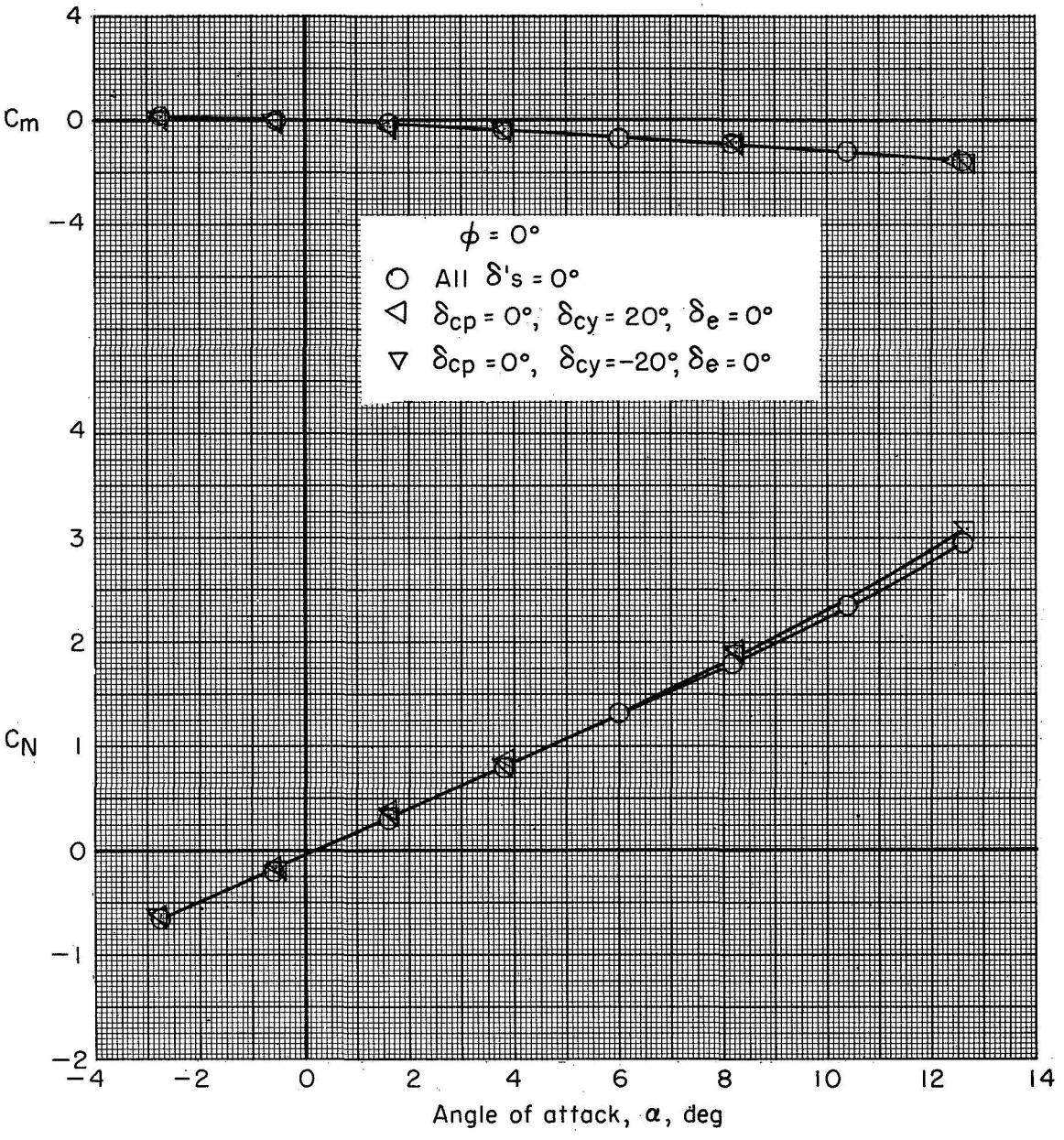
(a) Trailing-edge controls deflected for yaw only.

Figure 5.- Effect of combined pitch and yaw controls and yaw controls only on longitudinal characteristics.



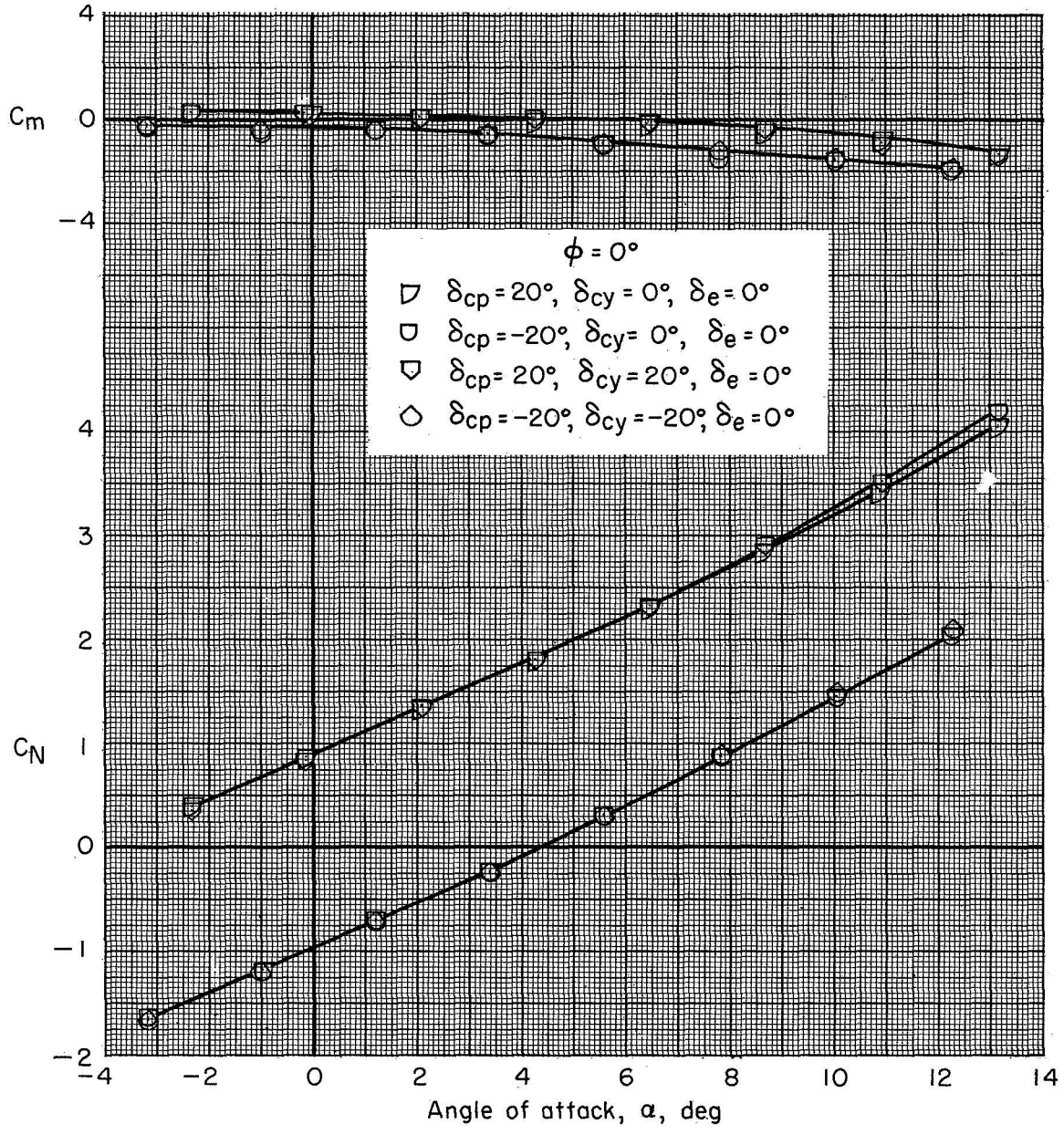
(b) Trailing-edge controls only deflected for combined pitch and yaw.

Figure 5.- Continued.



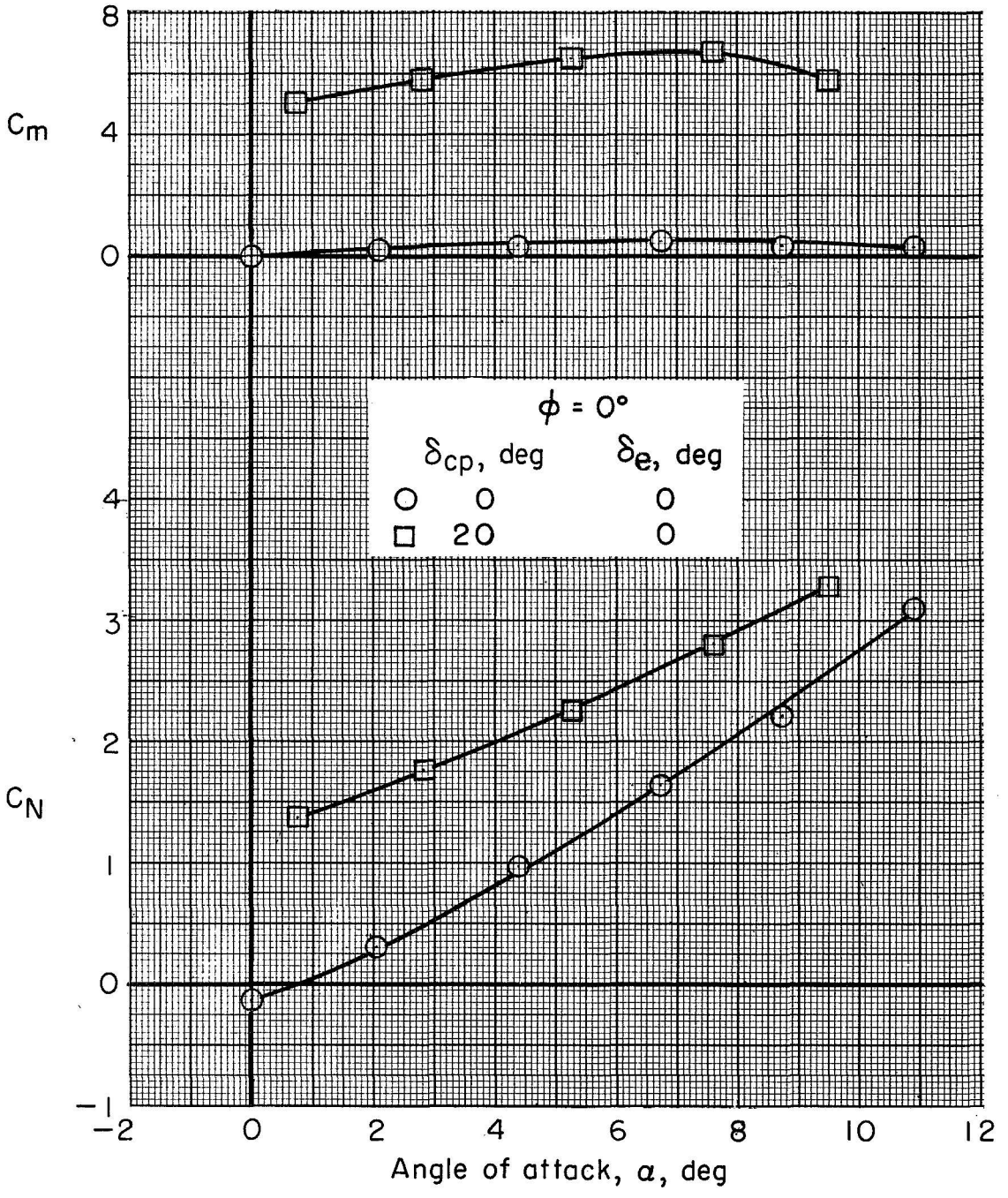
(c) Yaw canards only deflected.

Figure 5.- Continued.



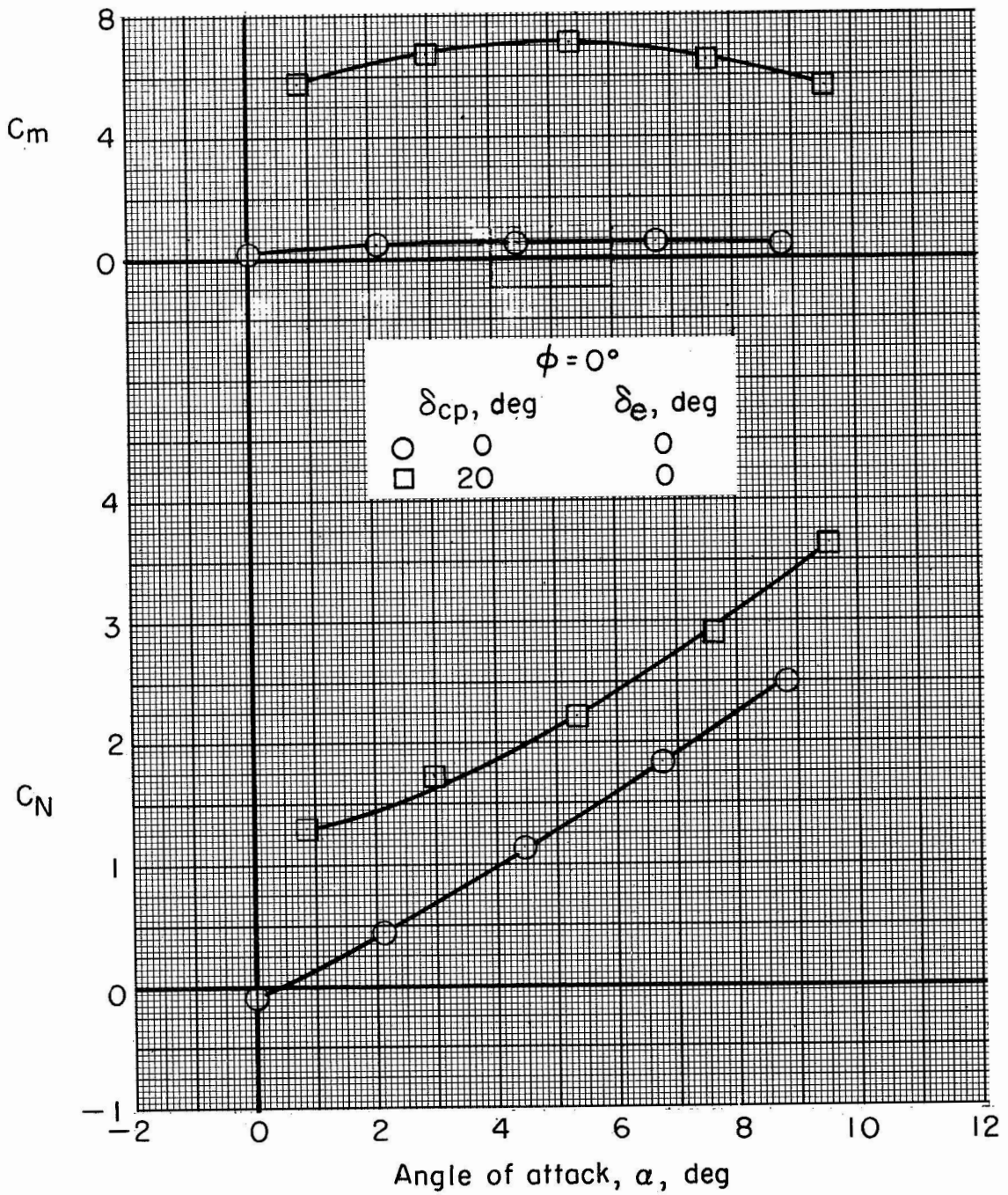
(d) Canard controls only deflected; comparison with and without yaw canard controls deflected.

Figure 5.- Concluded.



(a) M = 0.82, pitch canard controls only deflected.

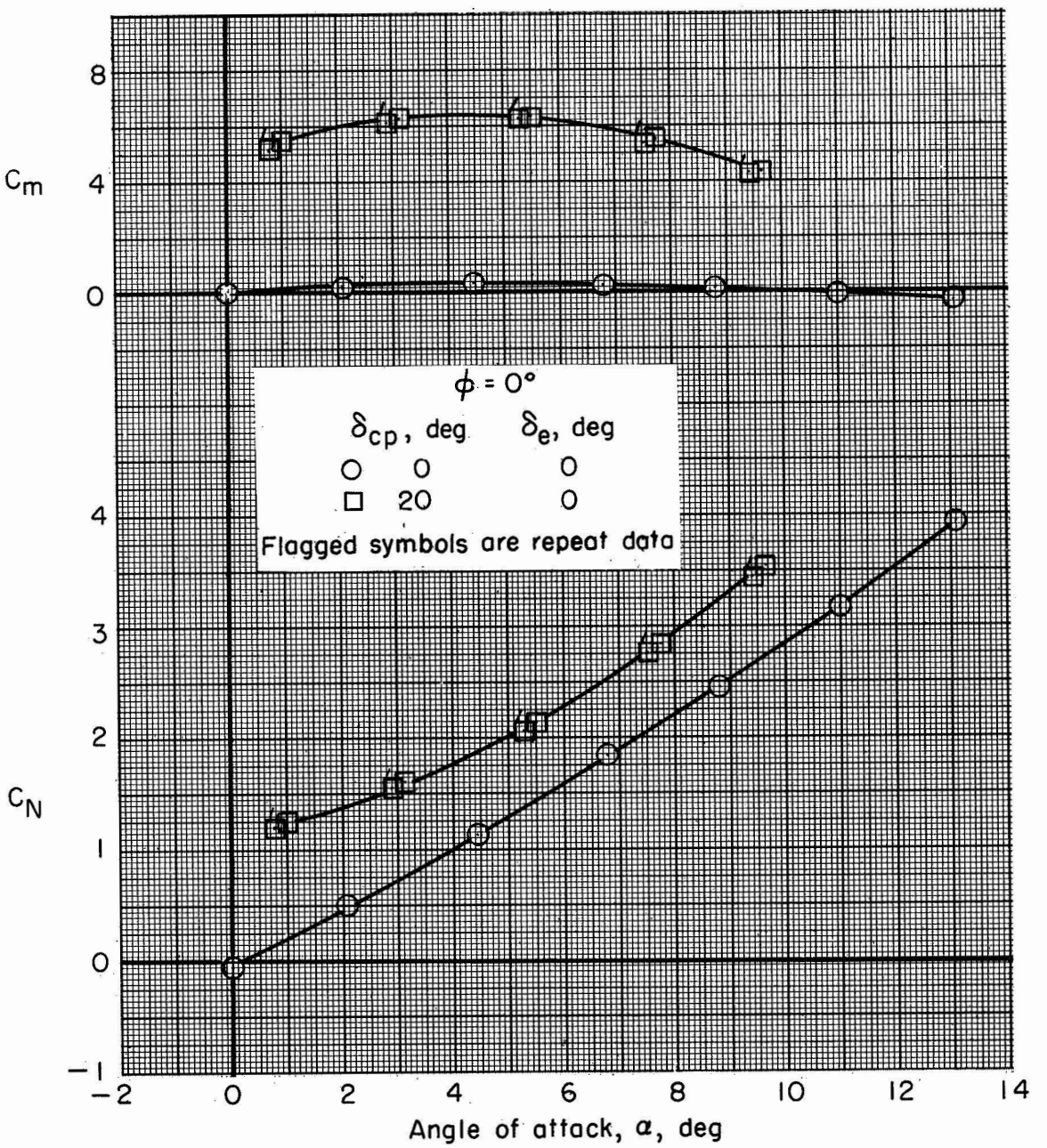
Figure 6.- Variation of normal-force and pitching-moment coefficients with angle of attack for several Mach numbers and control deflections, model 5.



L-651

(b) M = 1.00, pitch canard controls only deflected.

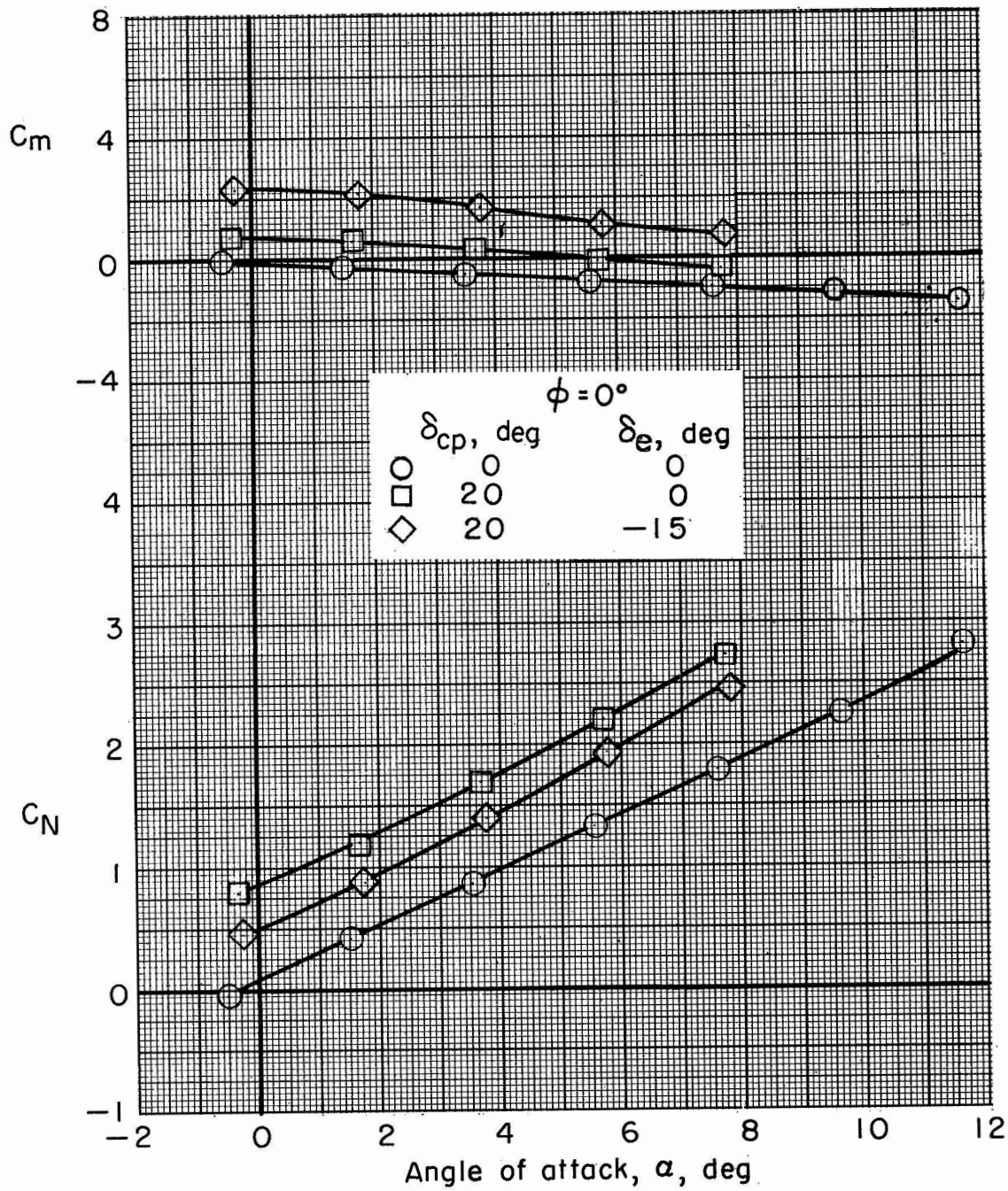
Figure 6.- Continued.



(c) M = 1.19, pitch canard controls only deflected.

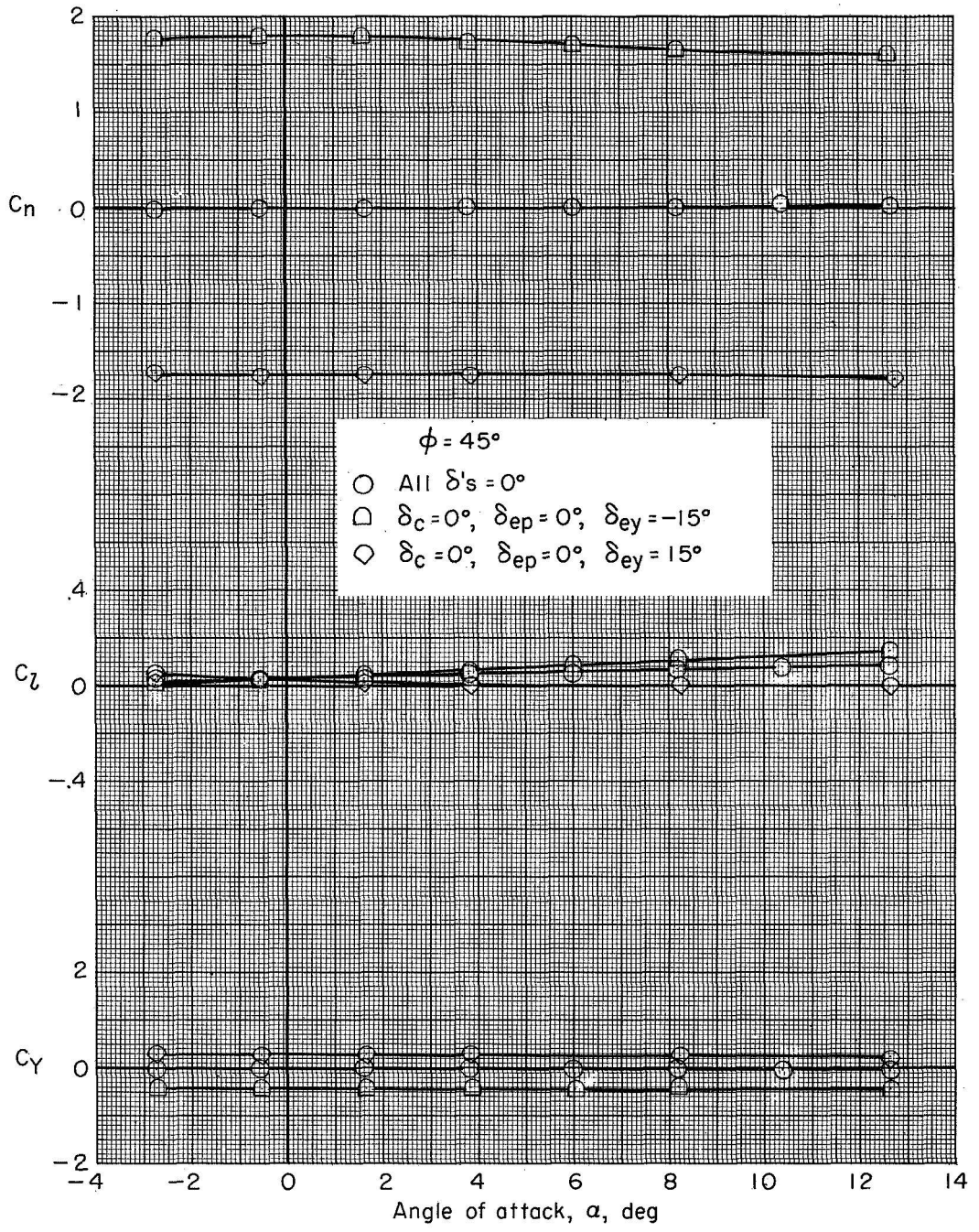
Figure 6.- Continued.

L-651



(d) M = 3.05, pitch canard controls and trailing-edge deflection.

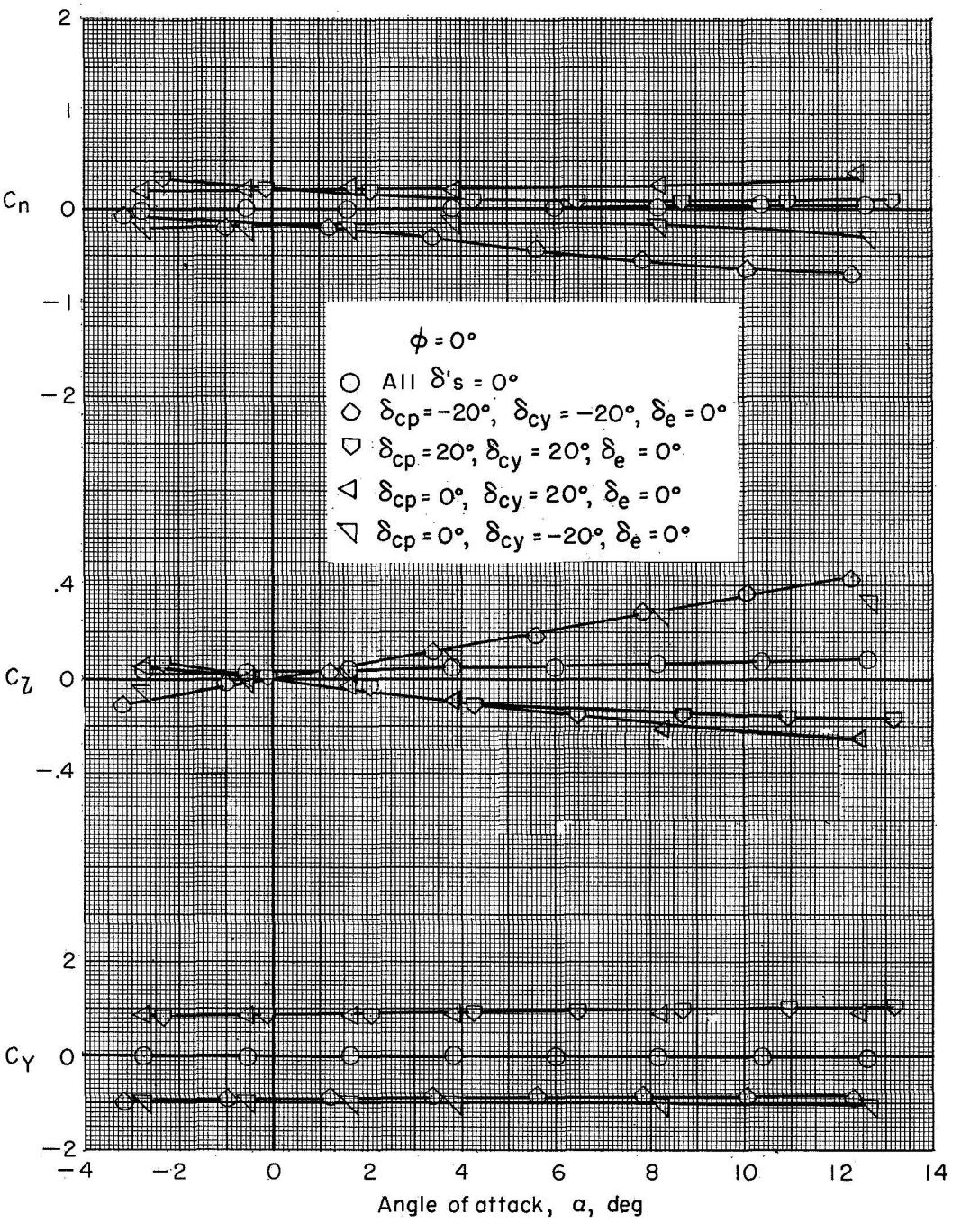
Figure 6.- Concluded.



(a) Trailing-edge controls.

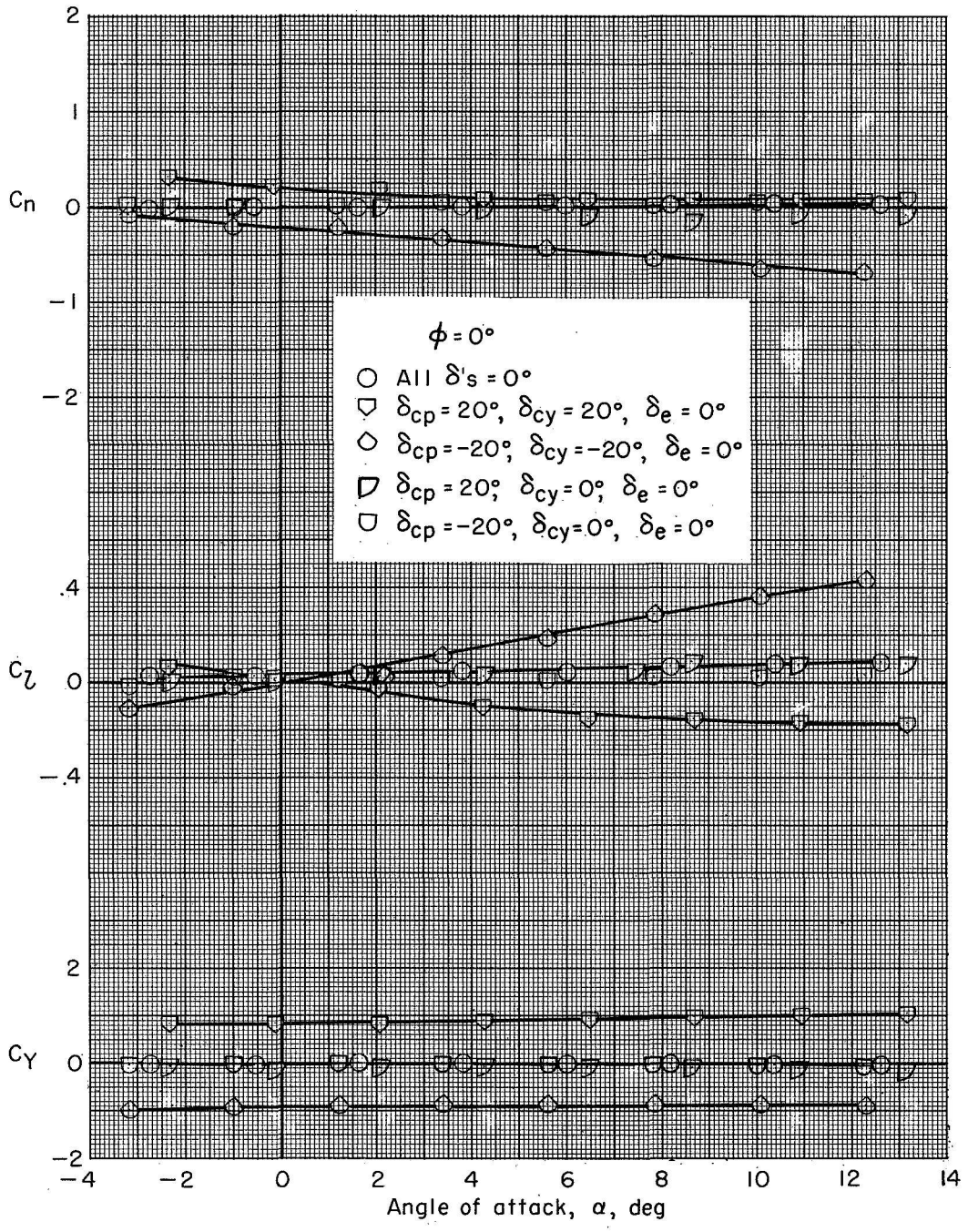
Figure 7.- Variation of lateral coefficients with angle of attack for model 4.

I-651



(b) Pitch plus yaw and yaw canard controls alone.

Figure 7.- Continued.

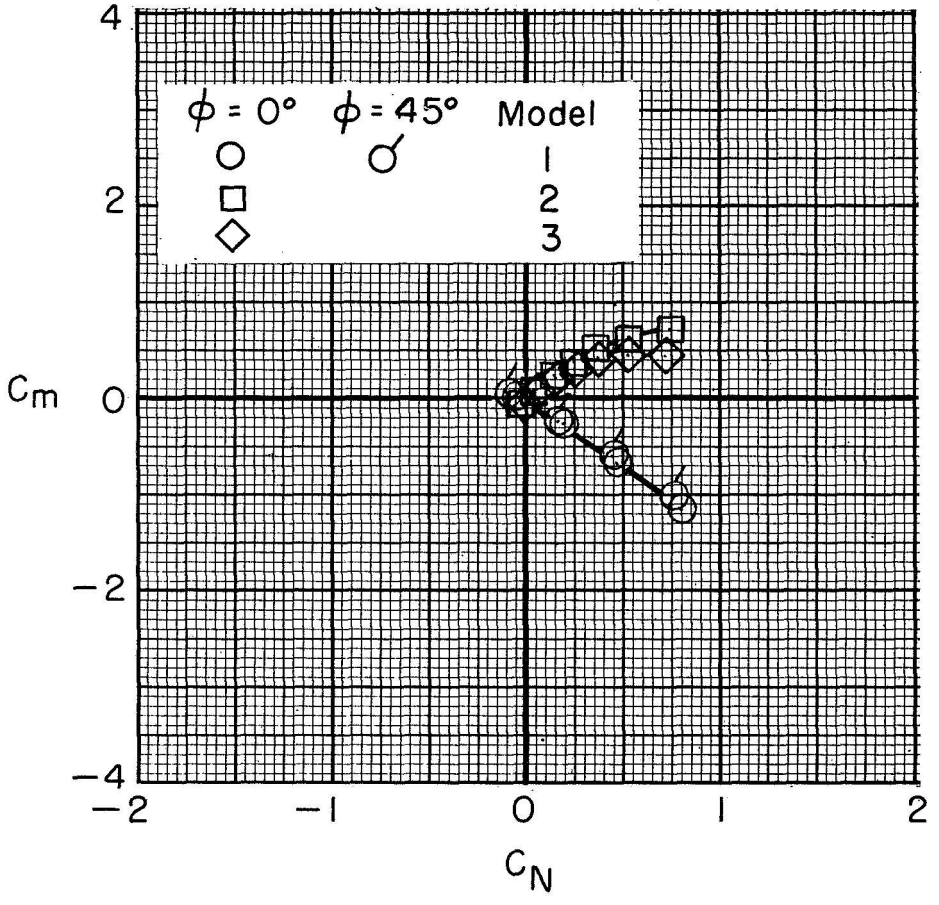


(c) Pitch plus yaw and pitch canard controls alone.

Figure 7.- Concluded.

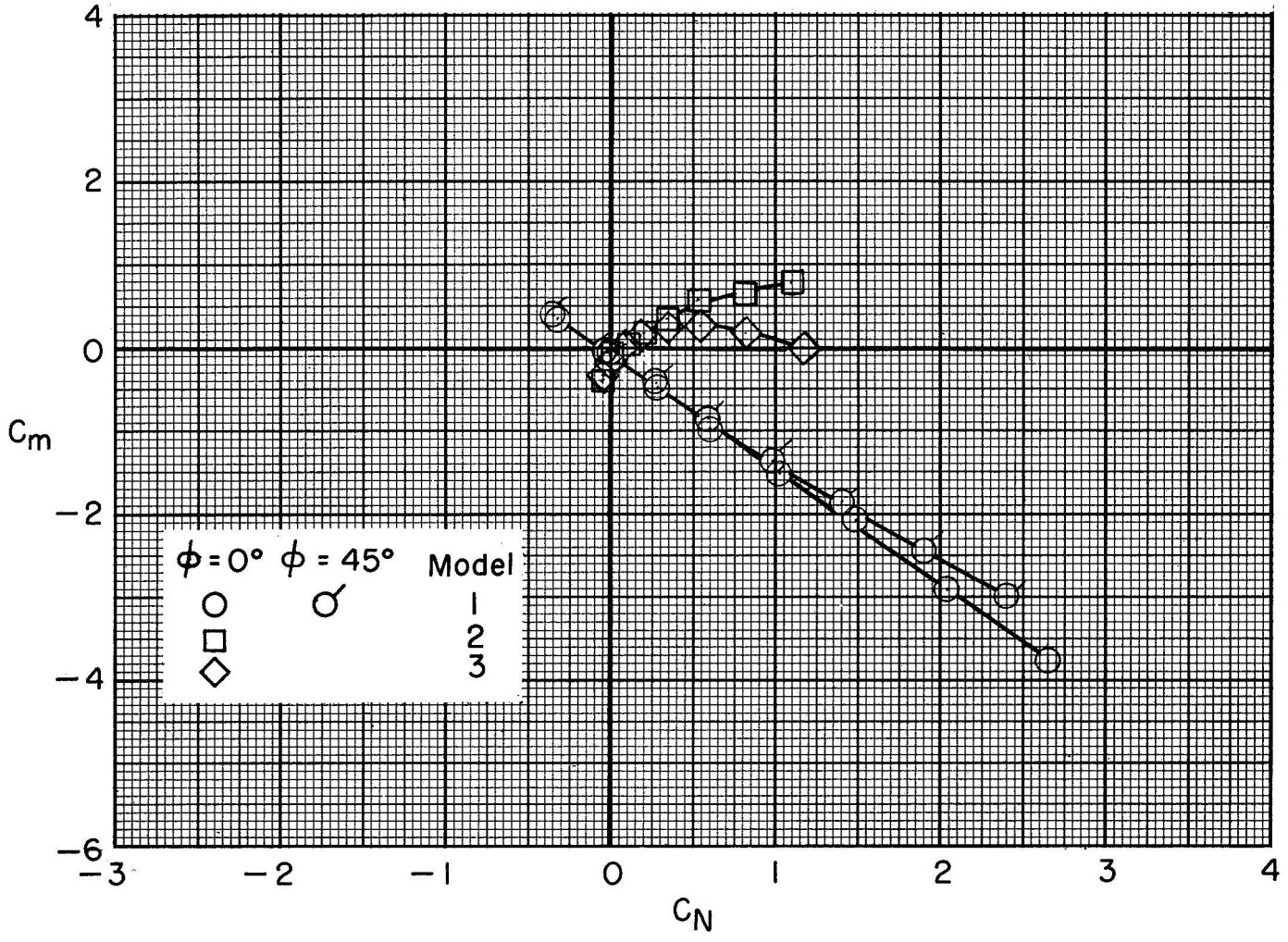
L-651

L-651



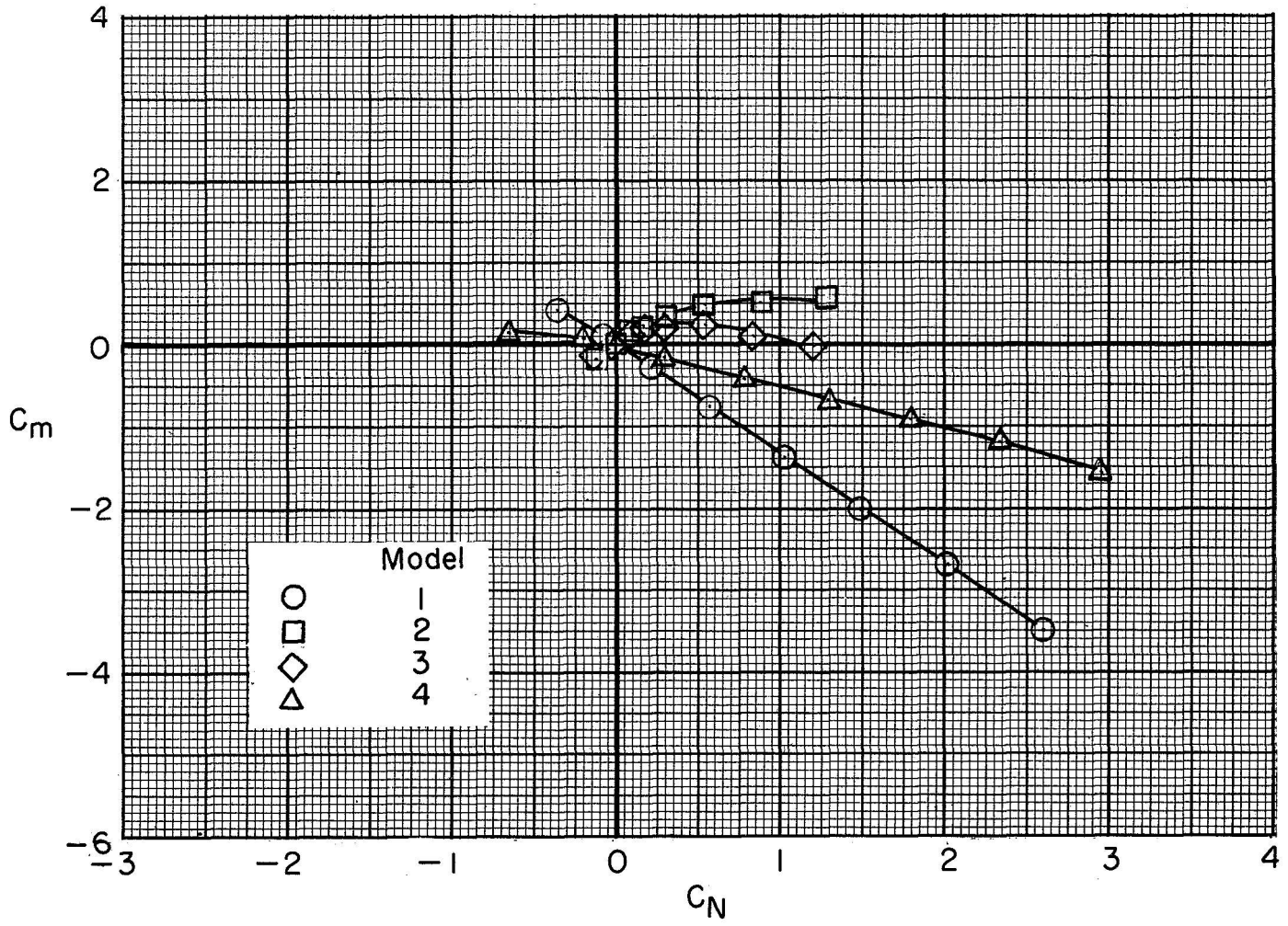
(a) Models 1 to 3 at M = 1.93.

Figure 8.- Static stability characteristics, no controls deflected.



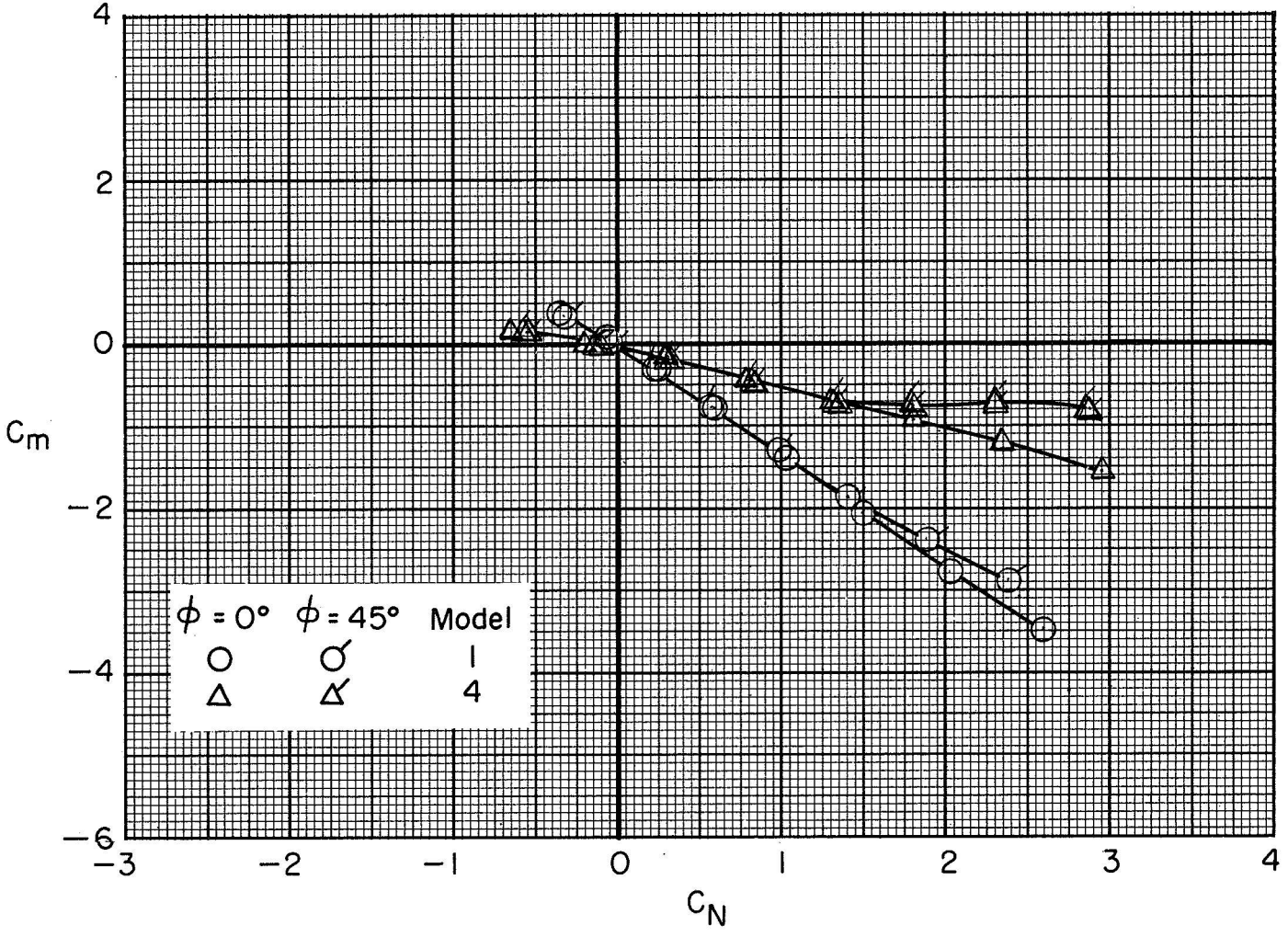
(b) Models 1 to 3 at M = 2.55.

Figure 8.- Continued.



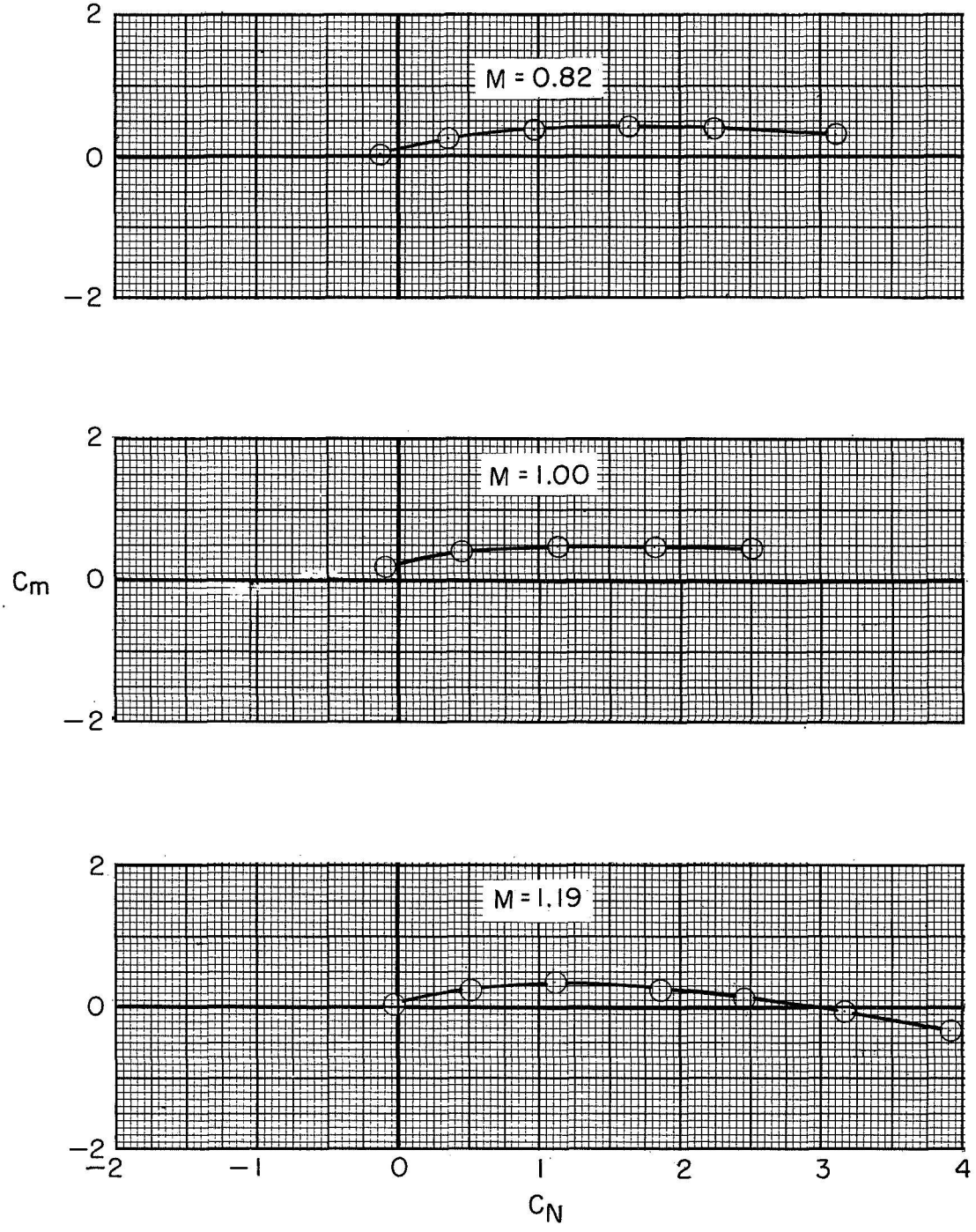
(c) Models 1 to 3 and 4 at M = 3.05.

Figure 8.- Continued.



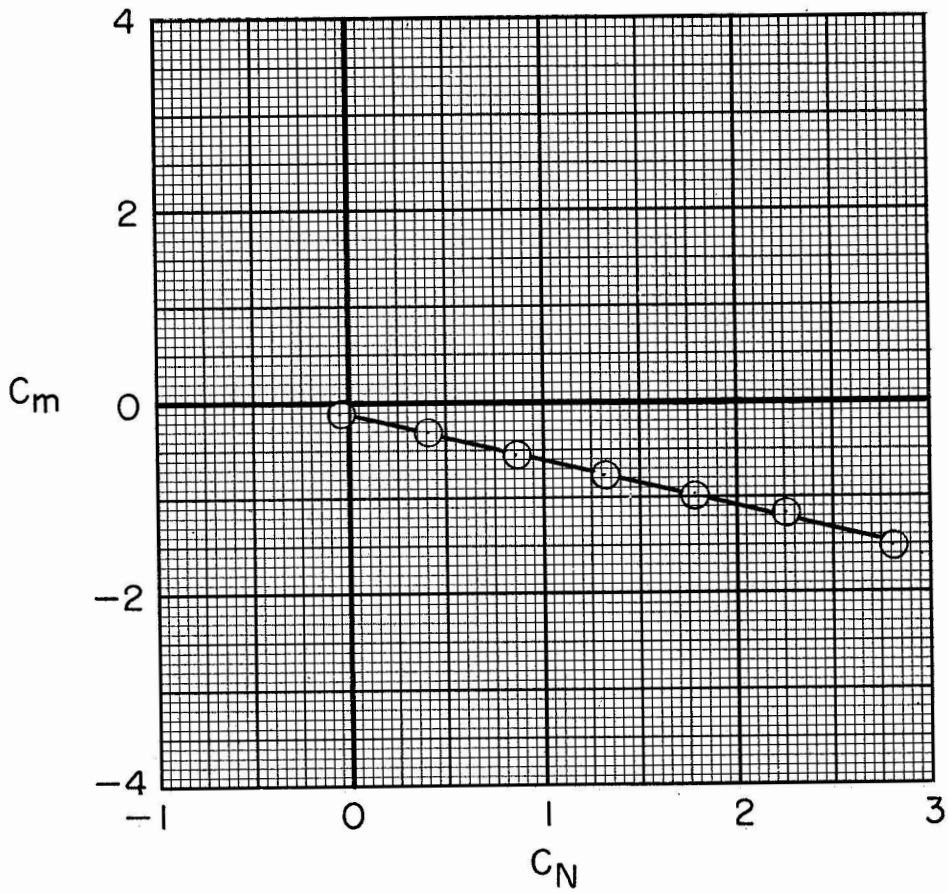
(d) Comparison of models 1 and 4 at two roll angles. M = 3.05.

Figure 8.- Continued.



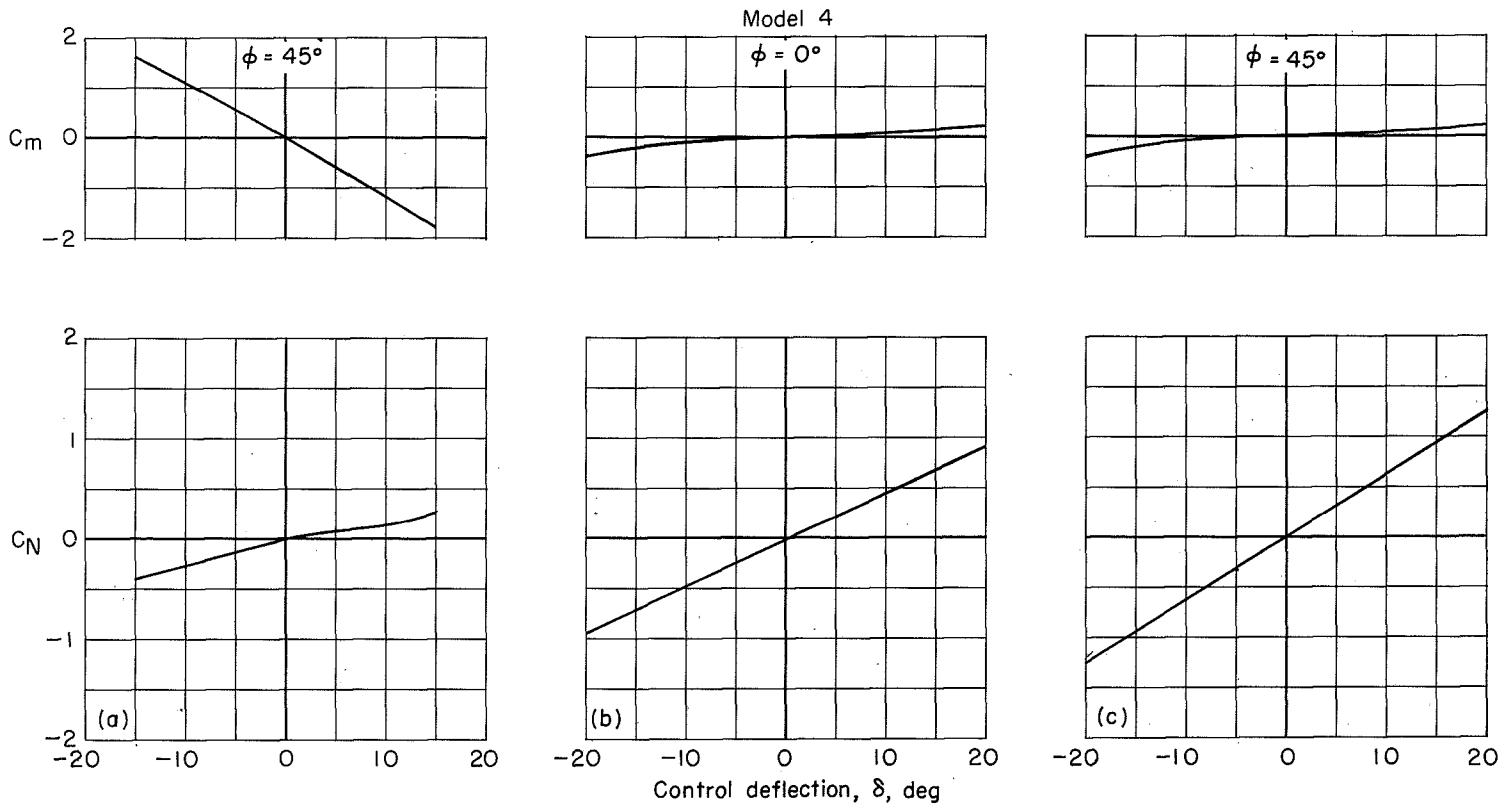
(e) Model 5 at M = 0.82, 1.00, and 1.19.

Figure 8.- Continued.



(f) Model 5 at M = 3.05.

Figure 8.- Concluded.

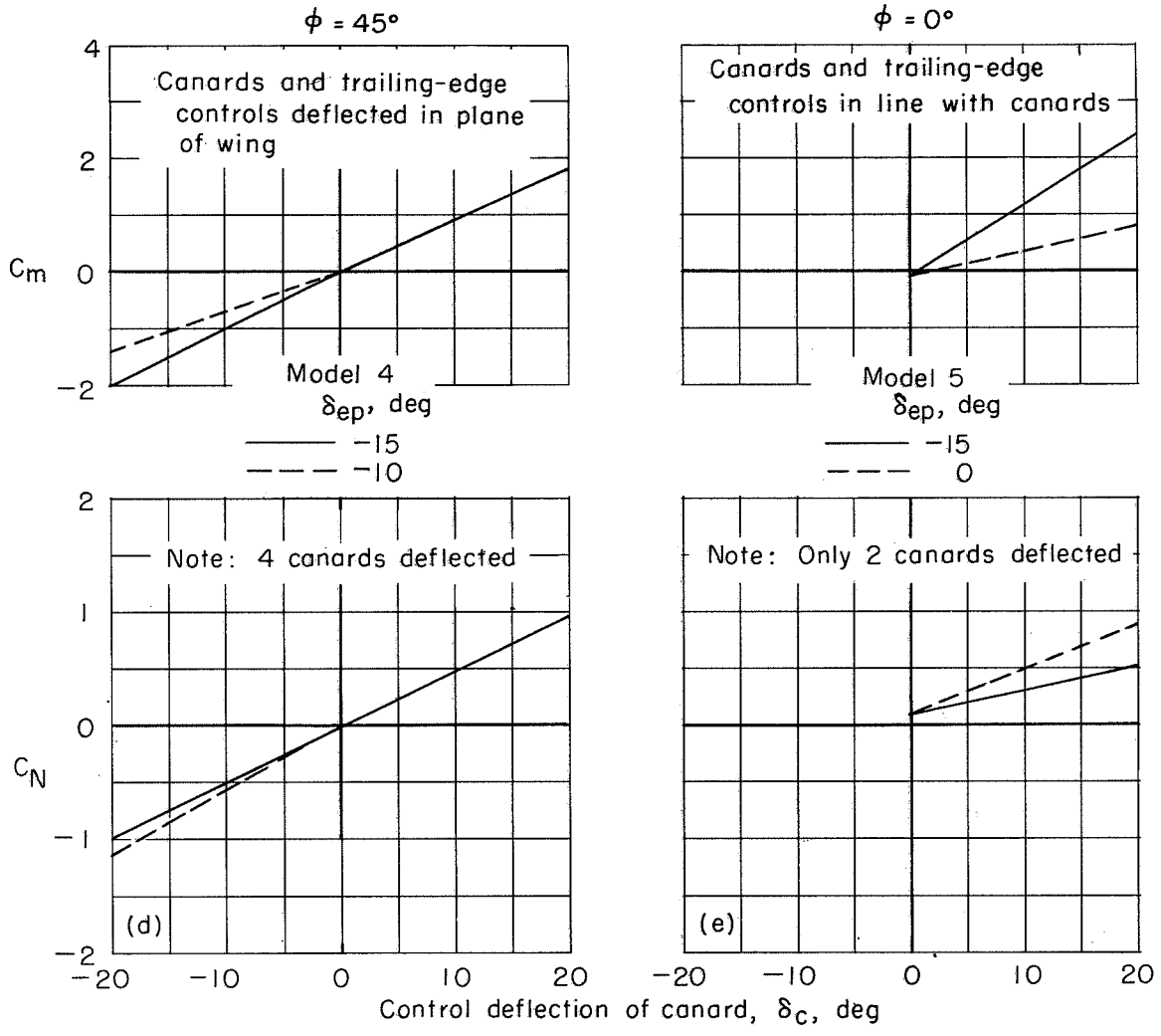


(a) Trailing-edge controls deflected.

(b) Two canard surfaces deflected.

(c) Four canard surfaces deflected.

Figure 9.- Longitudinal control effectiveness for models 4 and 5 at $M = 3.05$, $\alpha = 0^{\circ}$.

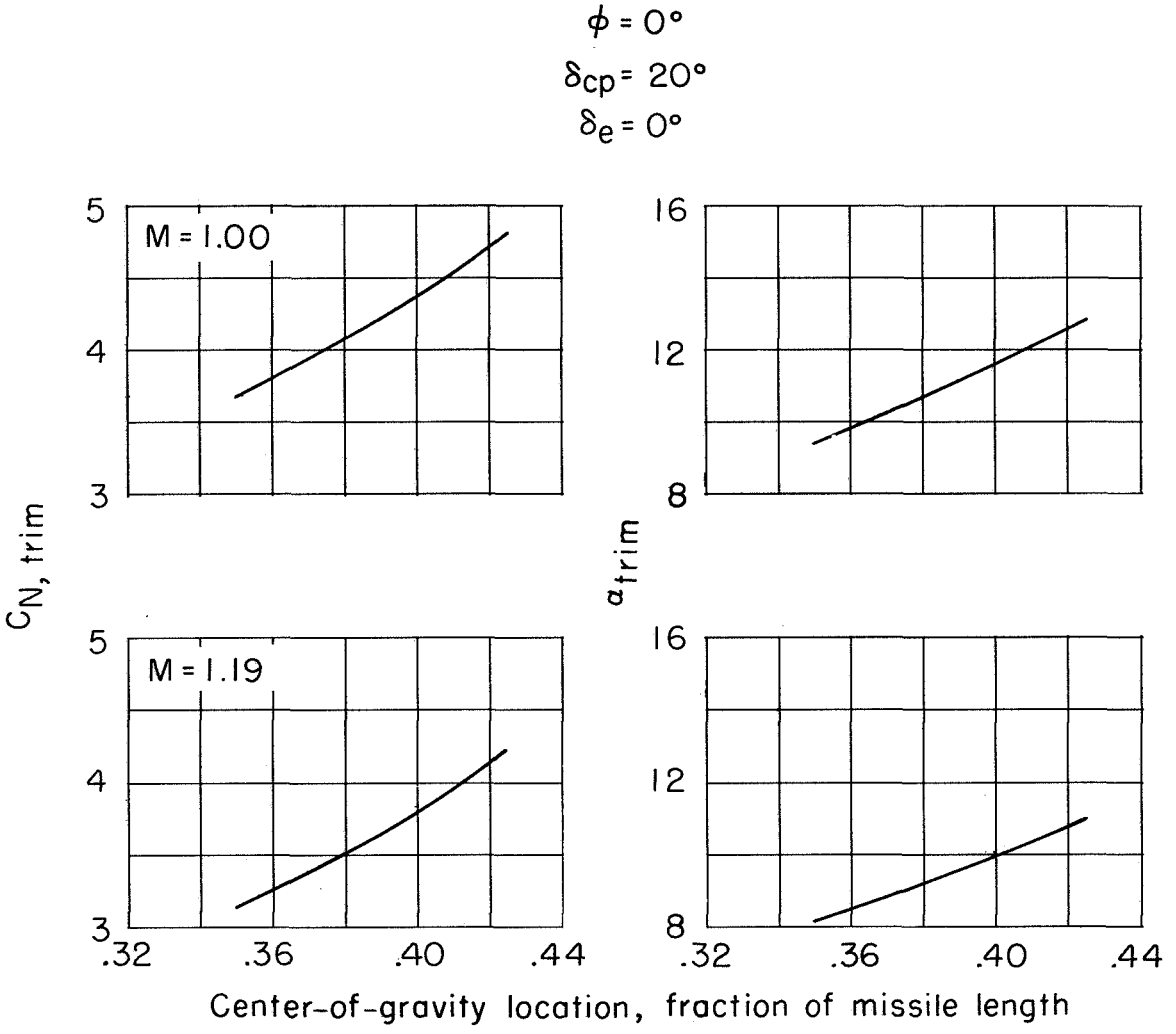


(d) Canard surfaces and trailing-edge controls deflected for model 4. ϕ = 45°.

(e) Trailing-edge controls in plane of canards and both deflected for model 5. ϕ = 0°.

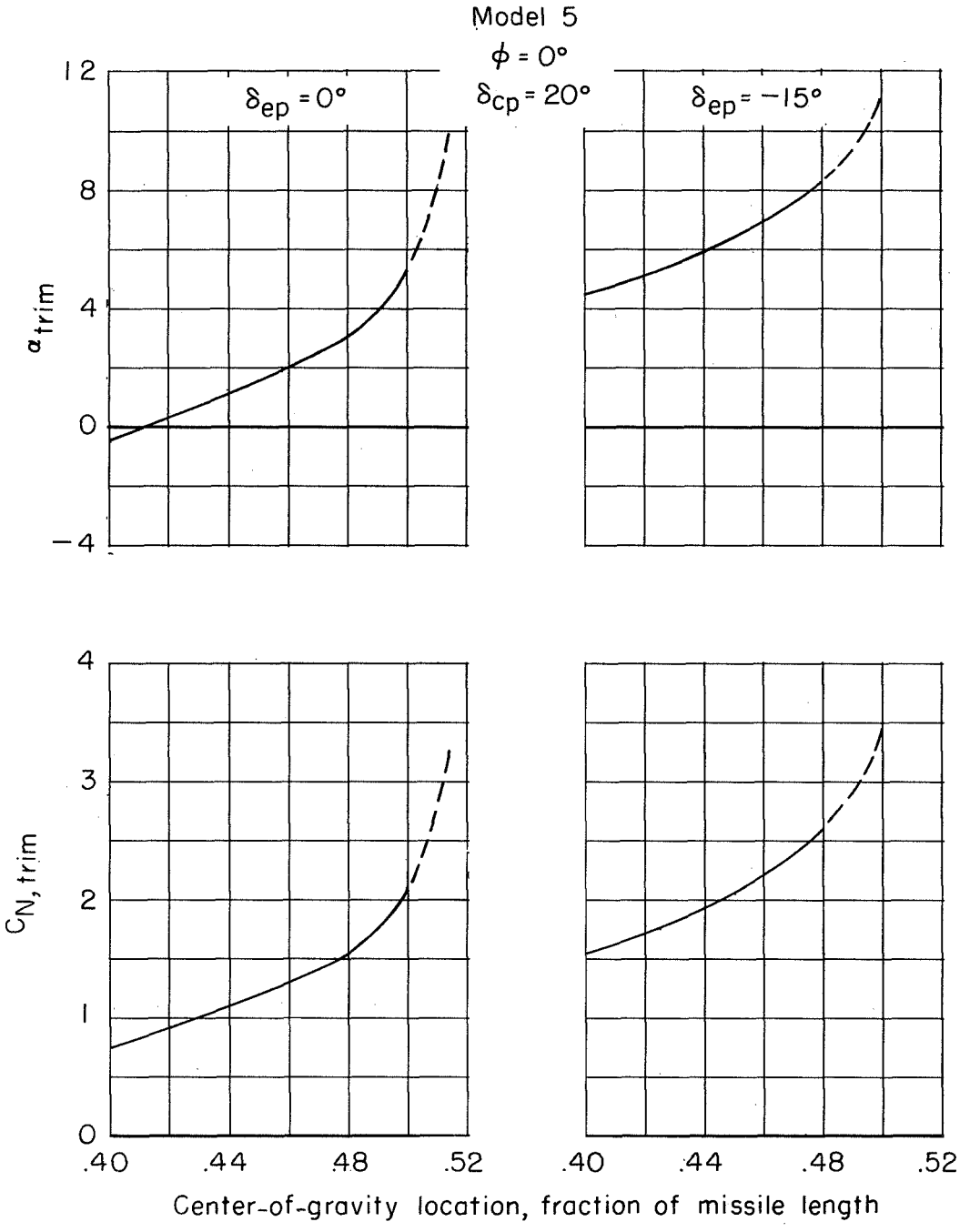
Figure 9.- Concluded.

I-651



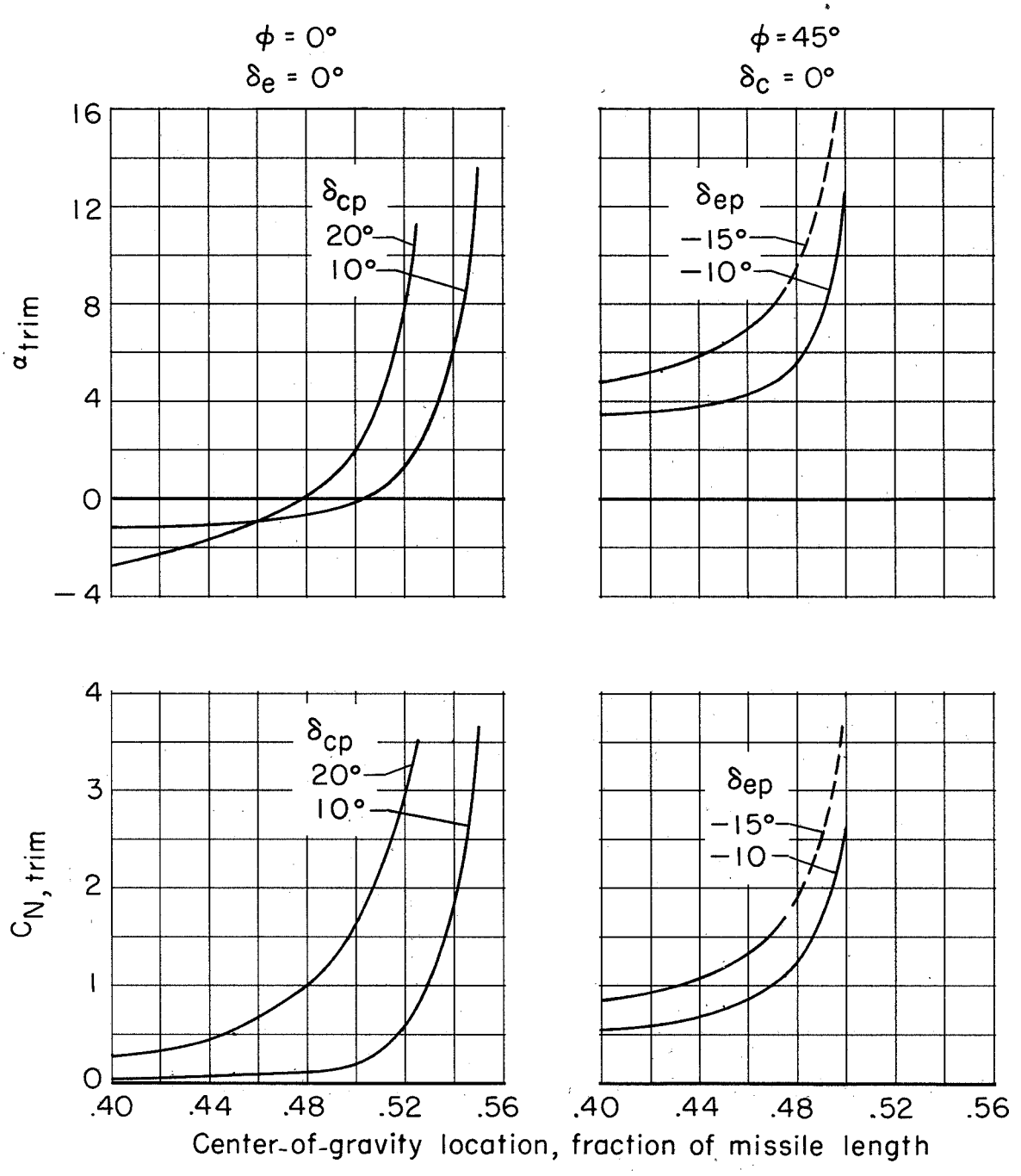
(a) Model 5; M = 1.00 and 1.19.

Figure 10.- Effect of center-of-gravity location on trim normal-force coefficient and trim angle of attack.



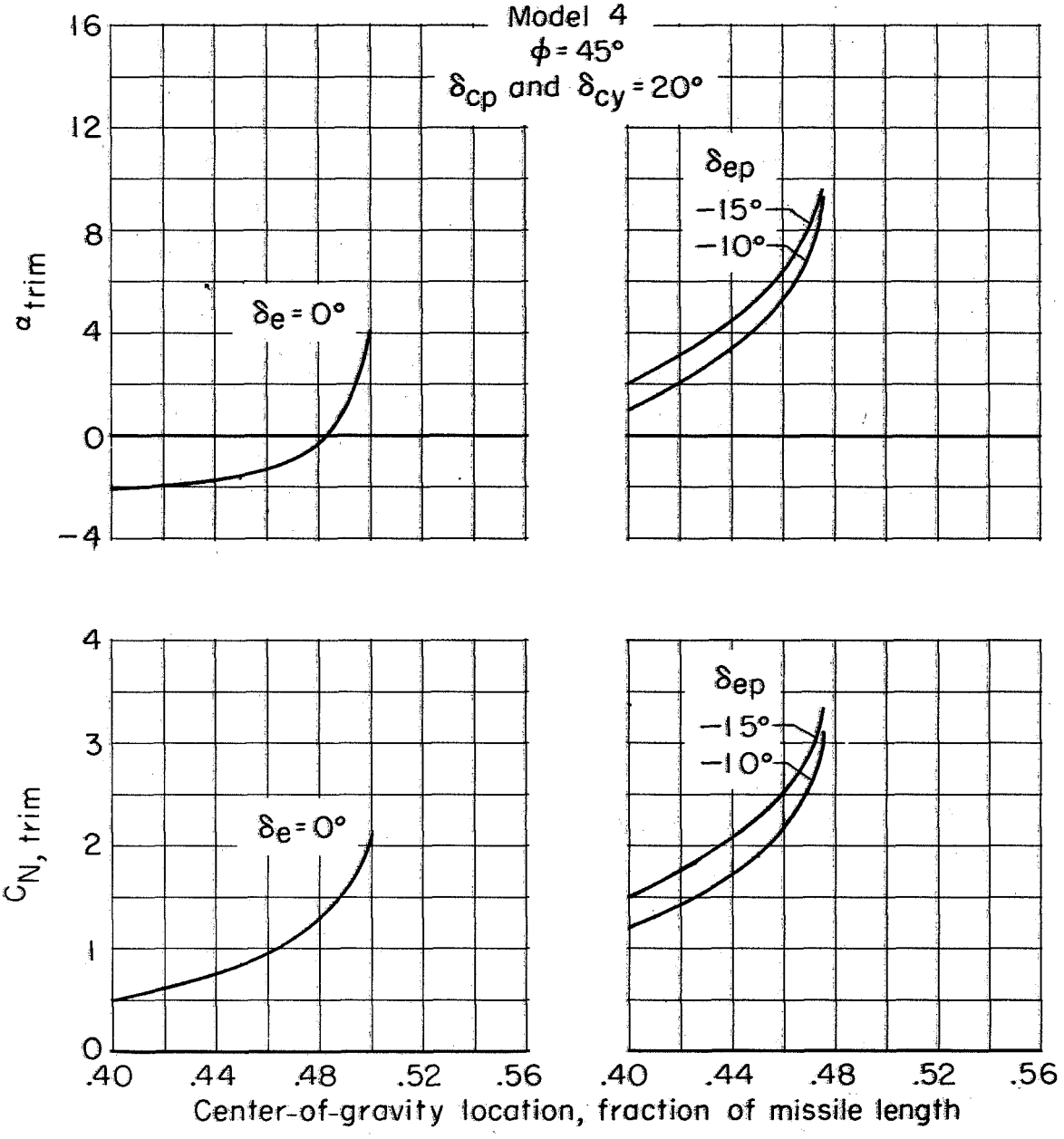
(b) Model 5; M = 3.05.

Figure 10.- Continued.



(c) Model 4; M = 3.05.

Figure 10.- Continued.



(d) Model 4; M = 3.05 (four canard surfaces deflected).

Figure 10.- Concluded.